LESSONS IN
PRACTICAL BIOLOGY
FOR
INDIAN STUDENTS

FIFTH EDITION

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LESSONS IN PRACTICAL BIOLOGY

FOR

INDIAN STUDENTS

BY

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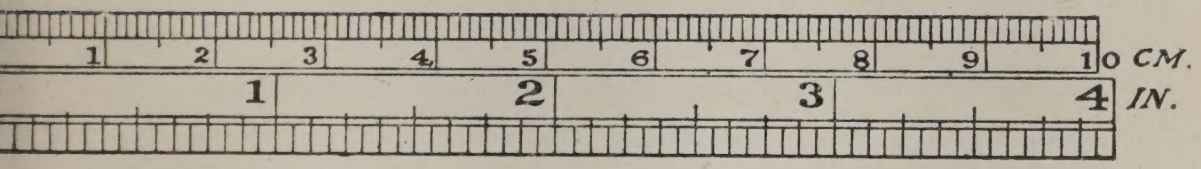

1 Kilometre	Km.	=	1000·0 M.	=	0·6214	mile.
1 Metre	M.	=	1·0 M.	=	39·37	inches.
1 Decimetre	dm.	=	0·1 M.	=	3·937	,,
1 Centimetre	cm.	=	0·01 M.	=	0·3937	inch.
1 Millimetre	mm.	=	0·001 M.	=	0·0394	,,
1 Micron	μ.	=	0·000001 M.	=	0·000039	,,

Or approximately—

1 mm. (millimetre)	=	1/25 of an inch.
1 cm. (centimetre)	=	2/5 of an inch.
1 inch	=	25 millimetres or $2\frac{1}{2}$ centimetres.
8 Km.	=	5 miles.
1 Micron	=	$\frac{1}{25400}$ inch.

Micro-millimetre, or micron :—the one-thousandth part of a millimetre ; the 1/25400th of an inch, often written μ.

PREFACE.

We offer no apology for the many repetitions to be found in the description of the types of animal and plant dealt with in the following pages ; they allow the student to examine them in any order convenient to him or to the teacher.

Most Indian students begin the study of Biology at a period when their previous study has been chiefly of languages, History,Geography or other subjects in which diligent reading and a retentive memory suffice to achieve success. Neither reason, experiment nor personal observation is called in to support or refute the dogma of book or tutor.

Hence, not unnaturally, the student is inclined to look upon Biology as a subject that can be learned in the same manner. Unfortunately, hitherto many teachers and examiners have encouraged this delusion and treat Biology as if it were a foreign language, their main object to cram the student with an unfamiliar and difficult terminology, most of which is by no means essential to a grasp of the principles of the science.

No amount of reading or lecturing will ever compensate for neglect of practical work in the laboratory and personal observation in the field, the only sound foundations for a knowledge of Biology.

We urge upon the student as he reads these pages that he must, whenever possible, keep on the table before him, the animal or plant under study and verify for himself our statements. When in doubt on a point in morphology, the Plant, the Frog or the Worm in question is a better authority than the text-book or the professor.

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AMŒBA.

Before looking for *Amœbæ* the student must first learn how and where to do so, otherwise he will waste almost as much time as in the proverbial search for a needle in a hay-stack.

Examine a drop of your own blood. Take some perfectly clean cover-glasses and slides. Clean the tip of your finger with a rag dipped in spirit ; let a friend grasp the finger pretty firmly when the tip will become red, and then prick it with a clean sharp needle (the needle may be rendered absolutely clean by heating it in a spirit or gas flame ; use when cooled). A minute drop not bigger than a pin-head should be squeezed out and touched with the cover-glass, taking care not to touch the skin. Let the glass then drop on the centre of a slide, when the blood will spread out in a thin film. In a well-made specimen the centre of the film should look as if there were no blood there. If the drop of blood that exudes be too big, wipe it off the finger with a clean rag or blotting paper and squeeze out a smaller drop.

If the drop be large, or if the surface of the cover-glass be dirty or greasy from touching with the fingers, the film of blood will be too thick and will not spread out evenly.

Examine under the highest power of your microscope. Note the pale yellow "*red corpuscles.*" Diminish the amount of light by using a smaller aperture of the diaphragm. Look for one of the *white corpuscles.* It will take some time for the novice to see them, but they are always present, and

he will eventually recognise them as colourless, transparent finely-granular bodies of irregular outline somewhat larger than the red corpuscles. Watch one and you will see it slowly change shape and the minute granules slowly change their position by a flowing movement.

Vary the amount of light by altering the diaphragm. You will probably find that, with very little light, you will see them best. Gently tap the cover-glass with a needle so as to set up a current in the blood. You will see the red corpuscles tossed about by the flowing plasma, but the white amœboid corpuscle stands fast unless the tap be too violent.

Three facts learned by the preliminary exercise will help you much in your hunt for the *Amœba*.

The white corpuscle of the blood (*a*) exhibits amœboid movements, (*b*) is very transparent and invisible in too bright a light, and (*c*) is adhesive to a glass surface. *Amœba* resembles it in all these three properties.

Take some of the water and mud from the bottom of a fresh water tank, add some withering leaves and stalks and expose to the sunlight for a few days.* With a pipette take a little water and mud from the bottom, or with the

---

* The medical student can obtain *Amœbæ* with little trouble in large numbers in the stools of certain cases of dysentery, especially when treated with salines. Great care must, however, be taken as there is a considerable risk of infection. When done with, the *Amœbæ* should be killed by heating the slide, and the hands should be disinfected. The under surface of the outer dead leaves of *Pistia*, the water-lettuce, when kept undisturbed for a few days frequently harbours many *Amœbæ*.

edge of a knife scrape the surface of a submerged leaf. Examine under a cover-glass with a half-inch objective, *using very little or oblique light*, and look out for an object resembling, but larger than, the white corpuscle. If in doubt about any object, *gently* tap the cover-glass. *If the object flows away, it is probably not an amœba.* Watch for a *flowing movement of the granules.* When an *Amœba* is found, put on your highest power and note—

There is an outer clear marginal substance known as the *ectoplasm*, (Gr. *ecto*, outer) so transparent that its margin may escape your notice. Move the mirror of the microscope to and fro slightly, and the margin may become more distinct. The central portion, of a ground-glass appearance owing to the presence of a large number of minute granules, is known as the *endoplasm* (Gr. *endo*, inner).

Watch the animal carefully and sketch it at short intervals. You will observe its outline change continually, and its position shift. At one or more places a little process of ectoplasm slowly projects. This is owing to a contraction of the rest of the animal, just as if you compressed some soft putty or dough in your hand, portions would be squeezed out between your fingers. At first only the ectoplasm takes part in this projection, but later the granular plasm will be seen to flow in with a fairly rapid rush. By this method the semi-fluid animal is able to change its position and move about with a slow flowing movement, so characteristic as to be known as "amœboid."

When the animal finds something it wishes to eat, it sends out on each side of the food one of these processes, known as *pseudopods*, (Gr. *pseudes*, false, *pous*, *podos* foot), which then

flow round and meet one another so as completely to enclose the particle of food. This becomes surrounded by a fluid which has the power of digesting or dissolving it. Any indigestible remnant is cast out in the same manner by the animal flowing away from it.

Should a grain of starch or globule of fat have been swallowed, it will be ejected quite unaltered, no matter how long it has been in the *Amœba*. From this it would appear that the animal is capable of assimilating proteid food only.

Amœba requires oxygen and gives off carbon dioxide, so we may assume that it breathes. It also excretes other waste products at all parts of its surface.

In many *Amœbæ* you may observe a clear round spot slowly form and increase to a certain size when it will suddenly collapse and disappear. This is known as the *contractile vacuole* (Latin, a little empty space). It again slowly forms and suddenly disappears rhythmically. Its formation is due to a collecting of fluid containing excretory matters, and its disappearance to the sudden rupture of the ectoplasm and the escape of this fluid. The vacuole is, as a rule, absent in the parasitic Amœbæ.

A darker spot, the *nucleus*, may be seen during the life of the amœba; but even when not visible its presence can generally be demonstrated by using certain stains, such as iodine, carmine, or many of the aniline dyes which stain the nucleus more deeply than the rest of the protoplasm.

Take a drop of water containing some amœbæ on a slide, put on a cover slip, run in a drop of a 0·5 per cent. solution of acetic acid tinged with methylene blue. This kills the amœba before it has time to withdraw its pseu-

dopods and shows the cytoplasm slightly, the nucleus more deeply stained.

The reproduction of *Amœba* is an extremely simple process, it simply divides itself into two, the nucleus always dividing first before the rest of the protoplasm. Each half becomes a new *Amœba* which feeds and soon grows to the size of its parent cell.

Under unfavourable circumstances, such as the drying up of the water in which it lives, *Amœba* becomes sluggish, and drawing in its pseudopods, assumes a globular shape. It then secretes a thin waterproof membrane on its outside, and goes into a state of rest in which its functions remain dormant. In this condition, called encystment, *Amœba* can be carried by the wind as a particle of dust to great distances till it again finds a suitable home. Sometimes instead of dividing into two (*binary fission*) the *Amœba* breaks up into a large number of small individuals each containing a fragment of the nucleus, when the process of multiplication is known as *sporulation* or multiple fission.

No *Amœba* can arise except as the offspring of another *Amœba*. This fact is as true, though not so obvious, of *Amœba* or any other animal or plant, no matter how minute or lowly, as of Man himself.

If some meat, soup or an infusion of vegetable matter be exposed to the air it is a matter of common knowledge that in a few days it will be found full of minute animal and vegetable organisms and in a state of decomposition. Not very long ago it was universally believed that animal and vegetable matters of necessity became rotten when dead and that this decomposition gave rise to new living organ-

isms. Now we know that it is these low organisms that cause the decomposition and not *vice versâ*. Canned vegetables and meat can be preserved for years; this might be attributed to the absence of air, but that it is not so can easily be proved. Take some cotton wool and a test-tube and submit them for some days to such a high temperature that any living organisms would be killed. Place some broth in the tube, plug the neck of the tube with the cotton wool and boil the broth for a few minutes twice daily for a few days. You will find that the broth keeps clear and "sweet" for an indefinite period. If you examine a drop under the microscope you will find no living animal or plant.

If the plug of wool be removed, the broth will be found next day to contain many small plants, called *Bacteria*, and later will become turbid and rotten.

This experiment shows that it is not the presence of air that causes decomposition, for the air is able to pass in and out freely through the spaces between the cotton fibres. The cotton has acted as a filter, so that no dust has been able to pass through the broth. Almost all dust contains numerous spores of yeast, bacteria and other fungi as well as encysted *Amœbæ*. It is the entry of these organisms into the broth and their subsequent rapid multiplication that have caused the decomposition.

This is an experiment which with many others should satisfy you of the correctness of the theory of Biogenesis, namely, that there is no "spontaneous generation" of any animal or plant, be it *Amœba* or Baby, *Bacillus* or Banyan tree. Every cell, every animal, and every plant is the offspring of a previously existing cell.

Occasionally an *Amœba* has been seen to flow round and enclose another of the same species. This which formerly was looked upon as an act of cannibalism, is now considered by many naturalists to be a primitive love scene or act of sexual conjugation. *Amœba* can be artificially multiplied by cutting it in pieces, provided there be a part of the nucleus in each fragment. Each piece develops into a new *Amœba*.

If a very diluted solution of some irritant chemical, such as iodine or alcohol, be run in under the cover-glass, the *Amœba* will be seen to draw in its pseudopods proving that it is irritable or sensitive to a stimulus. Gentle heat or electric shocks will produce the same effect.

We must now consider more particularly the substance of which *Amœba* is composed.

It is known as *protoplasm* and is the basis not only of *Amœba* but of all cells, animal and vegetable alike. We have seen it to be a soft viscous, semi-fluid substance not soluble in, but readily permeated by water.

It is of an extremely complex chemical composition but is not a definite compound with a definite chemical formula. On the contrary, we shall find one of its chief characteristics is that its chemical composition is continually changing, certain constituents being continually broken down, chiefly by oxidation, and others being constructed. These processes are known as *metabolism* (Gr. *metabolein*, to alter) ; the constructive as *anabolism*, the destructive as *katabolism*.

This mixture of compounds, protoplasm, invariably contains complex substances known as *proteids* or albumens, into the composition of which carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur invariably enter. It is

to these proteids that the chemical reactions of protoplasm are mainly due. Thus, like white of egg, a common proteid, protoplasm is coagulated by heat, by nitric, picric or chromic acids, by alcohol and other reagents.

It is soluble in weak alkalies and acids. In reaction it is slightly alkaline. When living it contains a large amount of water, abstraction of which causes its death.

Of its physical attributes *Amœba* has given us an illustration. We have seen it is capable—

(*a*) of growth,

(*b*) of assimilating food,

(*c*) of reproduction. It gives rise to offspring and is itself the offspring of a pre-existing parent.

(*d*) of responding to impulses or stimuli, or, in other words, it is "irritable."

(*e*) That it is motile.

(*f*) That it breathes or respires, *i.e.*, that it continually requires oxygen to unite with its carbon and hydrogen, as it were in a slow process of combustion, by means of which energy is set free.

These are the characteristics which distinguish all living things, animal or vegetable, from inanimate bodies.

To the Teacher.

Amœbæ cannot be obtained in pure culture but grow readily in symbiosis with many bacteria such as the Cholera vibrio or the Colon bacillus, on the following medium :—

Take " Lemco " or other Meat Extract	.. 0.5 grm.
Sodium Chloride	.. 0.5 „
Water	..1000 c. c.

Boil and filter. Add 10 c. c. of a 4 per cent. solution of caustic soda to render alkaline. Boil ; filter ; add 20 grm. agar-agar (sold in the bazaar as " safed ghas "). Boil again and filter ; pour into Petri dishes or test-tubes to form slants.

Obtain some *Pistia*, Water-lettuce, from a tank, scrape the under surface of some of the outer dead leaves and sow the scrapings on the surface of the agar.

On the second and third day the amœbæ are particularly active, many being of an elongated form moving rapidly with a worm-like rather than an amœboid movement.

Note that after the lapse of a week most of the amœbæ have become globular and motionless, while many are encysted. Make repeated transfers to fresh agar at intervals of three days.

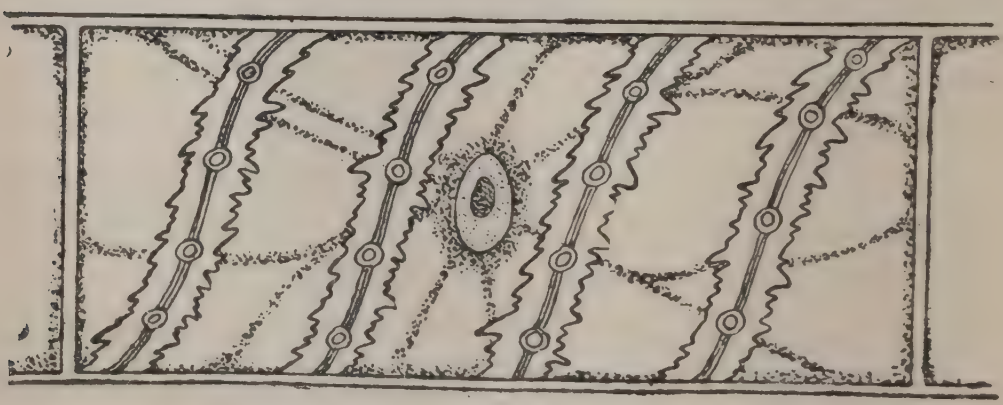
Note that the encysted amœbæ of a first transfer from a tank to an agar surface often fail to grow when transferred after two or three weeks to fresh agar, whereas after many generations grown on repeated transfers to agar, amœbæ though dormant and encysted for many months, at once grow with great luxuriance when transferred to fresh culture material.

SPIROGYRA.

In tanks and slowly flowing nullahs which contain clear water, you will often find slimy tresses of bright green, fine hair-like filaments which feel slippery to the touch. There are many genera of these water weeds, but under the low power of the microscope you can readily identify Spirogyra by the facts that it is unbranched and that its green colouring matter is arranged in spiral bands from which the plant takes its name.

The student should select a species in which the spirals are few and not so closely coiled as to obscure a view of the other contents of the cell.

Each filament is seen to be composed of a number of elongated cylindrical cells arranged, end to end, in a row. The essential part of each cell, as of all living organisms, is protoplasm. As is the case in nearly all vegetable cells, the protoplasm is enclosed in a *cell-wall* of colourless cellulose



Fg. 1.

readily recognised by its double outline. Owing to the presence of a large *vacuole* or central space filled with fluid, and of the green bands, the firmer portion of the protoplasm is not always readily recognised at first, but by careful focussing you will find a *nucleus*, perhaps containing a brighter central *nucleolus*, in the centre of this cell. Around the nucleus the *cytoplasm* can be recognised as a colourless granular substance sending thin processes out in all directions to the cell-wall and to certain spots in the spiral bands. Between these spidery processes is the large vacuole containing clear *cell sap*. The granular layer of cytoplasm lining the cell-wall has received, rather unnecessarily, the name of the *primordial utricle*. Constant movement of the protoplasm can be recognised by watching the darker granules passing along the strands of cytoplasm. The cytoplasm can be well demonstrated by the process of plasmolysis which depends on the varying osmotic powers of the different structures of the cell and the withdrawal of its watery contents.

Mount some Spirogyra in water under a cover-glass. Allow a drop of solution of sugar or of table salt (5 per cent.) or of saltpetre (8 per cent.), which may be coloured by adding a little eosine, to run in. The protoplasm will be seen to contract and withdraw from the cell-wall, beginning at the corners. At first the red colour passes through the cell-wall, but not through the protoplasm so that a layer of red fluid is seen separating the latter from the cell-wall. If now the saltpetre solution be removed and the Spirogyra be irrigated with tap water, the contracted protoplasm will recover and resume its original position. If, on the contrary, we allow the solution to remain, after an hour or two, you will see the

protoplasm begin to die and become stained by the eosine. The vacuoles will however resist for a much longer time, and be recognised as colourless globules in the stained protoplasm.

The same phenomena can be observed by the use of any fluid, such as glycerine or alcohol, which will withdraw by osmosis the cell sap, but these fluids kill the protoplasm more rapidly.

The cell-wall is composed of a colourless substance, cellulose, which like starch and sugar belongs to the group of substances known as carbohydrates, which contain only the elements carbon, hydrogen and oxygen, the two latter being in the same proportion as in water, *i.e.*, two of hydrogen to one of oxygen. Like starch it has the formula $C_6H_{10}O_5$ but is readily distinguished by the fact that iodine turns starch blue, while it stains cellulose slightly yellow. If in addition to the iodine, cellulose be acted on by sulphuric acid, it turns blue. This test should not be applied by the young student as he is liable to injure his microscope with the strong acid. Most vegetable cell-walls are composed of cellulose or one of its modifications. Cotton fibre is almost pure cellulose, and the student can test the chemical reactions of cellulose by soaking some cotton wool in iodine solution and then treating with 50 per cent. sulphuric acid. Another useful test is Schulze's solution of chloro-iodide of zinc which turns cellulose blue. Cellulose allows water and substances held in solution to osmose freely through it. It is insoluble in dilute acids or alkalies. By the action of strong sulphuric acid, it is turned into dextrose. It does not, like starch, swell up on the addition of boiling water.

The green spiral bands, which are known as *chlorophyll* bands, *chloroplasts*,* or *chromatophores*,† vary in number from one to ten. They owe their colour to a green pigment *chlorophyll*, which is present in all green plants. Each band is seen to have an irregular jagged margin and to contain at intervals round refractile‡ bodies called *pyrenoids*. If the plant has been recently exposed to sunlight each pyrenoid is surrounded by small starch grains which can be demonstrated by running in a little iodine solution. The starch granules, if present, will become blue or bluish black in colour.

Note that all the cells which compose a filament of Spirogyra are alike ; there is no apex, no base, no root to the plant ; each cell is in size, structure and function almost exactly similar to its neighbours. Hence we may look upon Spirogyra either as a colony of unicellular plants arranged in a string or as a multicellular plant in which under ordinary circumstances, there is neither differentiation of structure nor division of function between the cells. Each cell absorbs its own food without the aid of its neighbours, each is capable of dividing and multiplying independently.

REPRODUCTION.

Under normal circumstances Spirogyra reproduces itself by cell-division. This process usually takes place at night, but if we put the plant in a cool place, or surround the vessel with ice overnight, we can delay the division till next day and observe the process conveniently. While watching

* Gr. *chloros* green, *phyllon*, a leaf.

† Gr. *chroma* color, *phorein* to carry.

‡ A body is said to be refractile when the rays of light passing through it have their direction altered, as a result of which alteration, focussing with the microscope causes the body to glitter and appear dark alternately, according as the centre or the surface of the refractile body is in focus.

the process of cell-division you will observe the nucleus to divide first. Each half moves away from the centre of the cell, while a partition of cellulose is seen to creep in, gradually closing like the diaphragm of a microscope till it completely divides the mother cell into two new daughter cells.

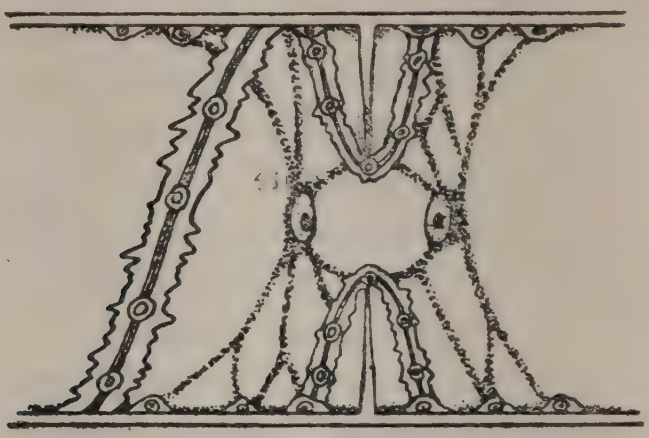


Fig. 2.

There is also a second, the *sexual*, method of reproduction which comes into play when the conditions for normal growth and cell-division become unfavourable as, for instance, when the supply of food or water becomes insufficient. You can recognise when this process is about to take place by the filaments becoming tangled, losing their gloss, and changing their bright green colour to a dull yellowish green. You will also notice on handling the plants that they are less slimy and have become somewhat gritty to the touch.

On examining with the one-inch power of the microscope you will see that several of the filaments have arranged themselves in parallel pairs. The cell-walls of most of the cells will have pouted out a protrusion which meets a similar protrusion from the cells of the neighbouring filament. The

cell-walls where these protrusions meet give way, so that a passage is made between each pair of cells. The protoplasm of one cell will now have separated from its cell-wall, contracted into an oval mass and lost its vacuole. It then moves through the passage into the other cell and the protoplasm of both unites to form a *zygote*.* This zygote becomes globular in shape and secretes a thick cell-wall composed of three layers, the outer and inner transparent, the middle yellowish brown. This coat is water-proof and prevents the protoplasm being killed by drought or frost.

The zygote can undergo a long period of rest and be blown about by the wind, till it finds a suitable place and temperature for germinating. The outer two coats then split, the protoplasm covered by the inner coat of cellulose grows out into an ordinary cell which multiplies by cell-division to form a filament of Spirogyra.

The essential character of sexual reproduction is that two kinds of cells known as *gametes*, (Gr. spouse, consort) separately incapable of further growth or development, meet together and their nuclei fuse, so that the two cells are inseparably united to form a single cell known as a *zygote*, (Gr. *zygotos* yoked, united) which now is capable of growth and development into an organism resembling its parents.

The union of gametes is spoken of as *conjugation*.

The gametes are generally of two kinds, male and female. The female generally has little power of locomotion, is therefore stationary, and being much larger than the male gamete, is known as the *megagamete*, (Gr. *megas*, large, great). The male in most cases is much smaller and is hence called the

* Gr. *zygotos*, yoked.

microgamete, (Gr. *mikros,* small). It generally has considerable power of locomotion owing to the presence of hair-like or whip-like processes of motile protoplasm called *cilia* or *flagella.*

In Spirogyra there is little difference in size or appearance between the two conjugating gametes, but one has greater motility than the other. The motile cell is therefore to be recognized as the male.

The female gamete whether of animal or plant, is very often called the *egg-cell* or *ovum,* (Lat. egg). The male, the microgamete, is called the *sperm-cell.* When it resembles a little moving animal or animalcule it is called a *spermatozoon* Gr. *sperma,* semen, seed; *zoon ;* animal) if it be the gamete of an animal. If the male gamete of a plant resembles a motile spermatozoon, it is called a *spermatozoid,* (Gr. *oidos* like).

When the contrast between the microgamete and the megagamete is obvious, their conjugation is often spoken of as *fertilisation* of the ovum by the sperm-cell.

An organ which produces gametes of any kind is known as a *gonad* (Gr. gonos, seed, offspring), or gametangium (Gr. *angeion,* case, receptacle).

If you have difficulty in finding conjugating plants in nature, you can easily encourage Spirogyra by artificial means to conjugate. Place some filaments in very little water in a sunny position, add sugar to the extent of 2 per cent. and allow the water slowly to evaporate in the sunlight only just adding from time to time sufficient water to keep the plants alive. In a few days you will find conjugating filaments.

Our view of the nucleus and cytoplasm is usually much

obscured by the presence of the chlorophyll bands, so we must study it further by fixing and staining specimens at successive stages of reproduction.

This may best be done by placing the plants for about twelve hours in a saturated solution of picric acid to which some strong solution of nigrosin is added till it becomes a deep olive-green colour. Aniline blue may be substituted for the nigrosin. Next wash out the excess of fixing and staining solution and then mount in glycerine. If you wish to keep the specimens permanently, ring the cover glass with varnish.

You have already seen how glycerine and alcohol plasmolyse protoplasm. A similar distortion will take place in the fixed and dead cells, if they be transferred suddenly from one fluid to another of widely different osmotic pressure. Hence we must always be careful to avoid distortion by gradually changing the fluid. In this instance, we may use successively 15, 30, 45 and 60 per cent. glycerine till the material is sufficiently transparent. Or we may suspend the material in the upper part of a tall vessel containing at first 10 per cent. glycerine, and at intervals add to the bottom of the vessel by a pipette, pure glycerine which will slowly diffuse upwards. Or we may place the tissue in a weak solution of glycerine and gradually condense it by letting the water evaporate. This can be done cleanly and quickly in the vacuum of an air-pump.

NUTRITION.

Chemical analysis shows us that Spirogyra contains the elements carbon, hydrogen, oxygen, sulphur and nitrogen with

smaller quantities of phosphorus, potassium, calcium and magnesium and a trace of iron. These elements are combined in various ways. For the chemical and physical attributes of protoplasm the student is referred to page 7.

We have seen that the cell-wall is composed of a carbohydrate, cellulose, ($C_6 H_{10} O_5$) and that the protoplasm has other inclusions, such as starch, sugar and chlorophyll.

It is obvious that the food of Spirogyra must contain all the above elements C. H. O. N. S. P. K. Ca. Mg. Fe., and if we analyse the water in which it grows we will find, in addition to the H2 O, a quantity of carbonic acid gas, CO2, and salts, such as nitrates, phosphates and sulphates of calcium, magnesium, potassium and iron as well as chloride of sodium dissolved therein. If a bundle of Spirogyra be washed clear of all earth, etc., under a running tap of distilled water and then placed in distilled water we will find no growth take place.

Dissolve ten grains each of magnesium sulphate, potassium nitrate and potassium phosphate in a pint of distilled water. Dissolve forty grains of calcium nitrate in another pint of distilled water and then mix the two solutions. A certain quantity of calcium sulphate will be precipitated, but we shall have some salts of all the above metals still held in solution.*

Wash some Spirogyra or other green water-weed and introduce it into the above solution. You will find that it grows and multiplies freely when exposed to sunlight and air.

It requires no further chemical analysis than burning some Spirogyra or any plant to tell us, by its charring, that carbon enters largely into the composition of all plants. But

* This is known as Knop's solution.

in the above solution carbon is the only essential element that we have omitted.* Whence does the plant obtain its carbon ? From the carbonic acid gas, which is freely soluble in water and is universally present in the atmosphere. If we boil the above solution so as to expel all CO_2 and then see that all the air with which it comes in contact passes first through a solution of caustic potash so as to remove any CO_2, we will find no growth of Spirogyra take place under any circumstances. You will also find that no growth takes place in darkness. Sunlight is essential for the growth of Spirogyra or any green plant.

Whence does the green plant obtain the energy necessary for building up its complex protoplasm ? All the above named salts, CO_2 and water are stable chemical compounds with little potential energy. You will notice that while green plants are growing in water in sunlight many small bubbles of gas rise to the surface. Collect some of this gas by inverting a glass funnel over some green water weeds in a glass tank; fill a test-tube with water and invert it over the funnel. On placing this apparatus in sunlight bubbles will ascend and displacing the water, collect in the tube. On testing you will find the gas is almost pure oxygen. Remove the vessel from the sunlight, or darken it with a screen and you will find the bubbles soon cease to be evolved. This proves that it is the light of the sun's rays that supplies the energy necessary for the assimilation of the plant's food. It is not the heat of the sun, for a thermometer will show no appreciable change in the temperature of the vessel when it is alternately

* As the amount of iron required is the merest trace, there is always sufficient in the Spirogyra introduced to last several generations.

darkened or exposed to the sun. This assimilation of carbon dioxide by chlorophyll is known by the name of photo-synthesis.

Take a bundle of Spirogyra filaments and wrap some tinfoil or lead paper round the central inch or two. Expose it to the sun in some tank water or in the above described Knop's solution. After three or four hours' exposure, mount a filament in a weak solution of iodine. Under the micros-cope you will see a layer of blue starch granules around each pyrenoid that has been exposed to the light but none in those that have been kept in the dark by the tinfoil. This proves that each chloroplast is a small laboratory in which with the aid of sunlight the protoplasm can construct starch out of CO_2 and H_2O. What the exact process is we cannot def-initely say, but the first visible result is starch. It is probable the substance first formed is glucose, grape-sugar, $C_6H_{12}O_6$ a carbohydrate like starch and cellulose, but unlike them, freely soluble in water. The chemical process which takes place in the chloroplast in the presence of sunlight may be expressed by the equation :—

$$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6\ O_2.$$

A part of the glucose is used up for the immediate needs of the cell, but most of it is rapidly converted into starch and stored up round the pyrenoids till wanted. In the higher plants such glucose as is not required for immediate use is collected in special store places such as the tubers of the potato, underground stems and the cotyledons of seeds. When wanted again the insoluble starch is converted into sugar, to be carried in solution to distant parts of the plant.

Starch has the same chemical formula as cellulose $C_6H_{10}O_5$ but differs from it in many chemical and physical properties. Take some commercial starch such as is used by dhobis for stiffening linen. Shake it up in water. You find it is quite insoluble either in cold or hot water. In boiling water it is still insoluble, but swells up to form a paste. Add a drop of very weak solution of iodine ; a deep blue colour instantly appears. On boiling the blue colour vanishes, but reappears on cooling. This forms a very delicate test for starch.

Cut across a potato tuber and with the knife scrape some of the sap from the cut surface ; examine it under the microscope. You will recognise numerous starch grains by the aid of the iodine test. Notice that most of the grains are ovate and many present a very distinct appearance of lamination round the hilum or organic centre. In the starch of the potato and of most plants this hilum does not coincide with the geometric centre but is usually nearer to one pole. Move the cover-slip gently so as to rotate the granules and you will find that they are only slightly flattened. Note that some of the grains have two or even three hila, each with its own concentric laminae ; a few have two hila, each with its own lamination, the two systems surrounded by common laminae.

Starch grains vary much in size and shape not only in different species but also in the same individual plant. Examine those from a grain of rice ; many are very small.

Cut across an underground stem of Canna ; examine a scraping from the cut surface ; you will find relatively huge starch grains. In oat flour you will see many pretty compound grains. In the milky juice of most Euphorbiaceous plants you will find many grains of a rod-and-bone shape. Starch grains are to be found in the plastids or chromatophores already described. In green leaves these are the chloroplasts ; here the grains are usually small ; in the deeper placed starch stores the grains are larger, the plastids colourless and therefore called leucoplasts. (Gr. *leucos*, white). Whatever the colour of the chromoplasts, they are all of the same nature. If a structure which normally lives underground, like a potato tuber, be exposed to sunlight it becomes " sunburnt " or green, owing to the leucoplasts producing chlorophyll. If a green plant be grown in the dark its leaves become blanched or " etiolated," owing to the chlorophyll disappearing from the chloroplasts which then resemble leucoplasts.

Chlorophyll can be obtained in solution by first boiling some green leaves in water and then extracting with alcohol, ether or benzol. The solution is strongly fluorescent, being greenish yellow by transmitted light, dark red by reflected light if in strong solution. Owing to rapid changes in its composition its chemical structure has not been determined. Though iron has not been found in its analysis, chlorophyll cannot form if the plant is completely deprived of iron. In that case the plant is bleached. On the addition of a minute trace of iron to the soil chlorophyll is speedily formed and the plant becomes green. The spectroscope shows that chlorophyll absorbs a large number

of rays in the red and in the blue and violet areas, as well as a few in the yellow and green, giving a very characteristic absorption spectrum: the chloroplasts thus rob the sun's rays of kinetic energy. Part of the energy is used by the chloroplasts to build up carbohydrates. This potential energy can again be set free by the decomposition of these compounds. Thus the heat evolved by the combustion of wood or other carbohydrates represents the energy obtained from the sun in photosynthesis. Each gain of growth by the plant is accompanied by a storage of potential energy on which the plant and each of its individual cells mainly depend for the carrying out of their vital processes.

RESPIRATION.

Respiration is a function necessary for all plants as well as for all animals. In its biological sense respiration is essentially a process of slow combustion in the tissues. As in the active burning of wood oxygen is required, and its union with the carbon and hydrogen of the wood gives rise to carbon dioxide and H_2O vapor, while the potential energy of the wood is set free in the kinetic form of heat: so in respiration, oxygen unites with the carbon and hydrogen in the animal or plant with the same result,—carbon dioxide is given off with watery vapor and at the same time potential energy is set free for the use of the organism. Students are apt to restrict the term, respiration, to the movements of our chests, but biological respiration is taking place all over our bodies. The movements of the chest are only mechanical devices in the higher animals to take in a large supply

of oxygen and to get rid of a proportionate amount of the gases of combustion. We can see men, frogs, cockroaches and Panuliri respire ; though we cannot see Amœba, Hydra, Spirogyra or any other plant respire, nevertheless respiration is constantly taking place in them all. During daylight the intake of oxygen in the green plant is so overbalanced by its output in the process of photosynthesis that we do not detect it, but in the dark when assimilation has ceased, respiration can readily be demonstrated if we carry out an experiment like that described later by the diminution of the oxygen in the air around the plant and by the increase of carbon dioxide. (P. 308) In plants like the Fungi, which have no chlorophyll, respiration is never obscured by photosynthesis and can be demonstrated at any hour by placing some mushrooms in that apparatus. The baryta water speedily becomes milky owing to the CO_2 given off by the respiration of the mushrooms.

PARAMŒCIUM.

Paramœcium can be found in any of the weed-covered tanks, *jhils* or borrow-pits of this country. It will also readily be found in great numbers in the stale water of vases in which cut flowers have been kept for some days. Examine with a low power of the microscope a drop of water obtained from one of these sources. The animal will be recognised as a somewhat flattened elongated body, two to four times as long as it is broad, darting about the field in a lively manner. If they be very numerous, a higher power of the microscope may at once be used to observe their more minute structure, but their movements are so rapid that only a momentary glimpse may be obtained as they dart across the field of vision.

Place a minute drop of a $\frac{1}{2}$ to 2 per cent. solution of eucaine or cocaine hydrochloride close to the margin of the cover-glass and allow it slowly to run in.

It is best to use a large cover-glass, as the weaker solution takes a long time to narcotise, and a strong solution kills the animals too suddenly.

With a large cover-glass and a small drop of stronger solution of cocaine, the animals nearest the drop are rapidly killed and broken up by a process of molecular disintegration or diffluence, very characteristic of *Infusoria*. The animal is seen to come to a stand-still, the cuticle gives way at one or more points, a little granular matter exudes, and the process continues till in a few moments nothing is left

but a patch of granular débris, in which no part of the animal can be recognised. As the cocaine slowly diffuses under the cover-glass, the animals at the far side will for a long time be unaffected, while those in the intermediate zones will be found in various stages of stupefaction. Long after locomotion has ceased, the movements of the cilia and contractile vacuoles can be seen.

The animal may also be studied by placing a drop of water containing *Paramœcia* on a slide, and spreading over it a few fibres of cotton to restrict their movements. Put on the cover-glass and examine.

If well done, the cotton fibres will act as fences, dividing the field into a number of minute paddocks, from which the animals cannot escape, but the method requires some experience, as if the wool be too little, the paddocks are too large, if the wool be too much, the animals can escape through the gaps caused by the crossing of the fibres.

A very convenient method is to drain off the excess of water under the cover-glass by tilting the slide and wiping off the water that runs out. After a time a little more of the water evaporates and the weight of the cover glass is just enough to keep the animals stationary.

MORPHOLOGY.

Note the size of the animal which varies in different species. Large specimens are just visible to the naked eye. *P. aurelia* is about 200 to 250 mikrons* in length, that is, about $\frac{1}{4}$ mm. or $\frac{1}{100}$ of an inch, but smaller specimens are common

* 1,000 mikrons = 1 millimetre = $\frac{1}{25}$ inch.

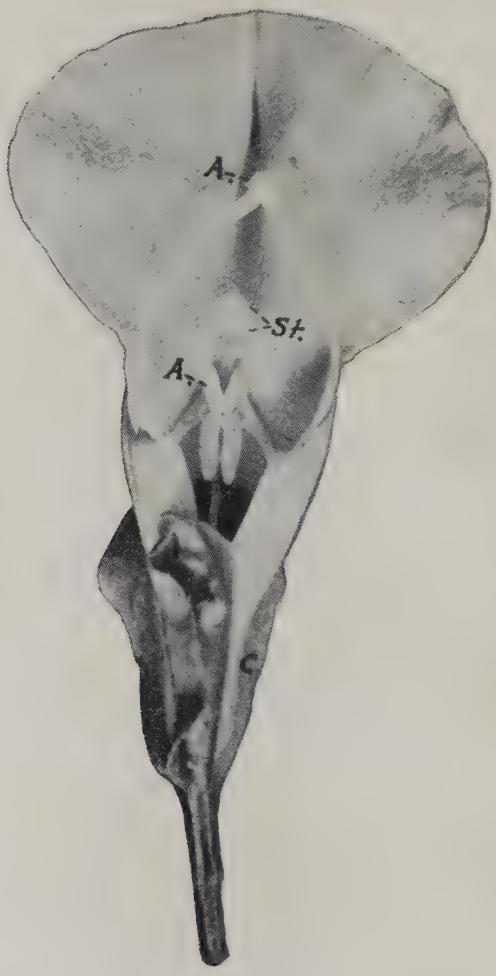


Fig. 100.—*Flower fo Torenia dissected to show the stamens and stigmas.* ×2.

A.—Anthers. *C.*—Calyx.
St.—Stigmas.

To face page 27

in our tanks. Though extremely flexible, the animal, unlike *Amœba*, preserves a definite shape and outline, the body being elongated and somewhat flattened. The *anterior* end, that portion which keeps in front during progression, is rounded, while the *posterior* end is usually somewhat pointed.

On the ventral surface, we find an oblique depression known as the *oral* or *buccal groove*, beginning on the left side near the anterior end and reaching backward to the mouth, which is a little behind the middle of the animal's length.

The cytoplasm is very clearly differentiated into an outer *cortex* (Latin, bark) or *ectoplasm*, and an inner granu-

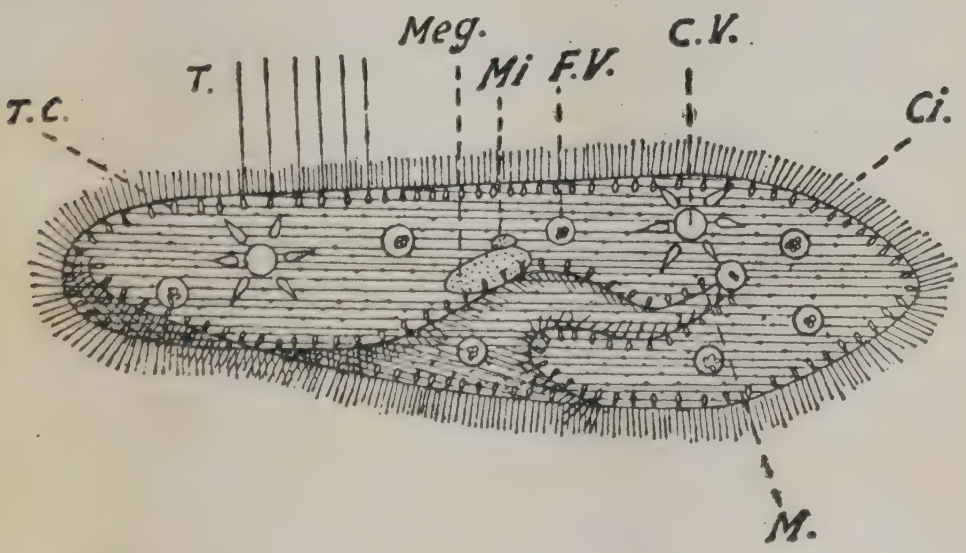


Fig. 3.—*Paramœcium*—Ci. Cilia. C. V. Contractile vacuole with radiating channels. F. V. Food vacuole. M. Mouth. Mi. Micronucleus. Meg. Meganucleus. T. C. Trichocysts. T. Discharged threads.

lar *medulla* (Lat. pith or marrow) or *endoplasm*. Externally the whole body is covered by a thin cuticle, through which

protrude numerous *cilia* (Lat. eyelashes) of approximately the same length.

These cilia are delicate hair-like filaments which vibrate to and fro without ceasing during the life of the animal. They arise from the ectoplasm, not from the cuticle through which they project. The movements of the cilia are extremely rapid, and somewhat resemble the waves caused by the wind in a field of corn or rice. Their mode of action is also easily explained by this simile. In the one case the current of wind causes a sudden bending of the elastic corn which slowly recovers its erect position only to be again bent by the wind. In the case of the cilia, the cause and effect are reversed. Their sudden bending, followed by a more leisurely return, sweeps a continuous current of water with the particles of food contained in it into the buccal groove, which also is lined with cilia, all working inwards to the mouth.

The ectoplasm is elastic and much firmer than the endoplasm. It is the protective, sensory and contractile layer. On its deeper surface may be seen indistinct longitudinal or oblique streaks known as the *myonemes* (Gr. *myon*, muscle ; *nema*, thread) or *contractile fibrils* by which the various bending and straightening movements of the animal are performed. To the myonemes and the rowing action of the cilia the power of rapid locomotion is due.

Observe the two contractile vacuoles in the dorsal portion of the cortex.

One is about one-third of the animal's length from the anterior end, the other about the same distance from the posterior. Each is connected with a number of radiating

channels which lead to it fluid for excretion. At the moment of contraction, or *systole* as it is called, these channels can be seen radiating out from the vacuole. After the collapse of the vacuole, the channels can be seen to fill gradually with fluid and then contract, discharging it into the vacuole, which becomes large and spherical in *diastole*. Both vacuoles then contract as a rule at the same moment and discharge the fluid externally. In some species they may be seen to contract alternately.

Run a drop of weak iodine, safranine or osmic acid solution under the cover-glass. You will see a number of stiffish threads several times longer than the cilia, suddenly shoot out. These are the threads of the *trichocysts*, (Gr. *trichos* a hair, *kystos* a bladder), stinging weapons used for offence or defence which are smartly discharged if the animal be irritated. The trichocysts are minute oval sacs arranged radially in the deeper part of the ectoplasm.

Run in a drop of 1 per cent. acetic acid. The same result will take place. Stain with safranine. The lashes of the discharged trichocysts are now well seen.

A little finely powdered indigo or carmine should be suspended in the water to observe the action of feeding. Those particles which enter the buccal groove will be seen swept down by the action of the cilia to the mouth, where they pause for a moment. A sudden gulping movement is seen to take place, and the next moment the particle of indigo is seen in the endoplasm surrounded by a droplet of fluid known as a *food vacuole*. Many of these vacuoles may be seen circulating in the endoplasm till their contents are digested. You may see that starch grains and droplets

of fat are digested as well as proteid matters—a considerable advance on the assimilative powers of *Amœba*.

The fæces, or waste food, from which the nutriment has been extracted, are discharged at a definite spot, a little behind the mouth. This is not a permanent opening and is called the *anal spot*.

The endoplasm is much more fluid and granular than the ectoplasm. The circulation of the food vacuoles and granules has already been noticed.

To observe the presence of the large nucleus with the small nucleus close by it, run a drop of half per cent. acetic acid under the cover-glass.

Stain the specimen with carmine, safranine or methylene blue. With an oil-immersion lens, observe that the large oval meganucleus stains uniformly, while the small micronucleus shows the chromatin strands seen in ordinary nuclei.

Reproduction is effected by transverse fission. The large nucleus divides into two by direct division, the small nucleus divides into two by the complicated process of mitosis.* A transverse constriction appears and gradually deepens till the animal is completely divided into two, each new animal taking half of both large and small nuclei.

In many species of *Paramœcium* there are two micronuclei, and in others two meganuclei as well, throughout life and not only at the time of fission.

REJUVENESCENCE.

Reproduction by transverse fission cannot go on for

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* See page 226.

ever. After several, perhaps a couple of hundred, generations produced by fission, the capacity for reproduction in this manner seems to become exhausted. You may then observe two individuals become attached to one another by their ventral surfaces. The protoplasm of their bodies becomes continuous, and they swim about for some time in this position of *conjugation*. They then part and become separate individuals again. Very important changes take place during this elementary form of love-making, as a result of which both animals become "rejuvenated" and again capable of rapid reproduction by repeated fission.

During this conjugation the large nucleus breaks up into many fragments which disappear. Apparently some are absorbed, but in some cases they have been clearly seen to be extruded from the anal spot.

The micronucleus divides into two by mitosis, each of these again immediately divides into two, so that each of the conjugating individuals now possesses four micronuclei. Three of these disappear like the "polar bodies" of the higher animals, of which you will learn later on. The fourth again divides into two *pronuclei*, of which one, the female, is stationary, the other, the male, active. The conjugating *Paramœcia* then exchange their active pronuclei, which leave the animal in which they arose and cross over into the body of the other party, where each unites with the stationary pronucleus to form a single *zygote* nucleus (Gr. *zygotos* yoked, united).

Thus each of the conjugating cells comes to have a nucleus derived half from itself, half from its conjugating partner.

After separation the zygote nucleus gives rise to a normal mega—and micronucleus, and the rejuvenated animal is able to give rise to further generations by fission.

This process of conjugation seems to come on at some definite "rutting period." For weeks you may not see a single case of conjugation, when suddenly a large number of *Paramæcia* seem to fall in love, and after a little preliminary flirtation quite an epidemic of conjugation takes place.

We have seen in *Amæba* little differentiation of structure; there are no special organs for special functions, except perhaps, the contractile vacuole, and this is not present in many species, for example those parasitic on man.

There is no mouth, no hand, leg, stomach or lung. Perhaps it would be correct to say it is all mouth, all hand, all leg, all stomach, all lung, as any part of the *Amæba* seems equally capable of taking in food, digesting it, or of acting as an organ of prehension or locomotion.

Each individual mass of protoplasm, containing a nucleus, is called a *cell*. All animals and all plants are composed of such cells; some may be of a single cell such as *Amæba* and *Paramæcium* among animals or *Yeast* and *Bacterium* among plants; others are made up of many cells, but no matter how large or how complicated they may be, each Banyan tree, each Man himself begins his individual existence as a single cell, and it is only by the *multiplication* and *differentiation* of that cell and its daughter-cells that the higher animal or plant arrives at adult condition.

In *Paramæcium*, we find that though composed of only one cell, that cell maintains a definite outline, and that definite parts are set aside for definite purposes. We have

a definite spot, the mouth, into which all food is received, contractile vacuoles in definite situations, cilia set apart as special organs of locomotion, and other special contractile fibrils, the *myonemes*.

In higher animals composed of many cells, we find special collections of cells, known as *tissues*, united in various ways to form *organs* for special purposes.

These organs, tissues and cells are constructed on different plans to fit them for their special duties or *functions*, so that from their appearance we can generally tell what is their purpose. This fact may be expressed as a rule in Biology, that a division of labour is always accompanied by a differentiation of structure. Furthermore we find that this division of labour among cells or tissues that have become experts tends to efficiency, and that those animals and plants that show least division of labour or differentiation of structure are the lowest and most primitive in the scale.

A parallel may be drawn with human social communities. In a savage or " primitive " state each man is a " Jack-of-all-trades." He does his own hunting, killing and cooking, he makes his own weapons, furniture, hut and clothes, he is his own doctor, law-maker and policeman to protect himself and his property. In a slightly higher state we find hunters, warriors, slaves as tillers of the soil, the women as cooks and rudimentary dressmakers and tailors, and our own prototype, the medicine-man who is not only druggist, surgeon and physician, but priest also in many cases.

In higher states of Society we find still further specialisation. For instance in most parts of this country the druggist, doctor and priest are differentiated into three per

sonages. In large cities we find the medical man further specialised, the surgeon, the physician, the gynæcologist, the sanitarian, till finally in the great cities of Europe we have specialists for the eye, ear, throat and almost every organ in the body. A similar or even greater specialisation is found among the employes of our cloth, iron and ship-building trades.

History, even personal observation in countries like Japan, teaches us that the highest and most specialised form of civilisation is descended and developed from the more primitive. All the most civilised countries have passed by gradual development from primitive savagery to their present high estate.

THE YEAST PLANT.

If a drop of the freshly drawn sap of a Toddy Palm be examined under the microscope no organised structure will be seen.

Examine the same sap a few hours later, and you will now see floating freely in the fluid, a large number of globular or oval bodies somewhat smaller than human blood corpuscles. Each of these bodies is a small plant known as Saccharomyces or the Yeast plant, which is almost universally found in earth and dust.

On examination with a high power each plant is seen to be a small speck of colourless protoplasm surrounded by a cell-wall. In the protoplasm can be seen a number of fine granules and probably one or more vacuoles.

Allow a little Iodine solution to run in under the cover-glass. You will note that the cell-wall remains unstained while the central protoplasm stains brown. No blue dots are to be seen, therefore no starch is present. Stain another specimen with fuchsin, you will see the protoplasm stain red, the vacuoles being colourless or showing a faint pink colour, owing to a thin layer of stained protoplasm surrounding them. Stain another specimen with osmic acid solution. Many of the dots in the protoplasm turn black showing they are droplets of fat. No nucleus can be seen in these stained specimens or in the living unstained cells, but one is present and can be demonstrated in the following way.

Allow a thin smear of yeast to dry on a slide. Place the slide in alcohol for a few minutes, then in ether or petrol and again in alcohol. Then stain with Romanowsky's stain or hæmatoxylin. The nucleus will now be easily recognised as a central dark-stained spot.

Plants like Yeast, Mucor and Bacteria do not contain chlorophyll and do not show any differentiation of their body into root, stem or leaves. Such plants are known as Fungi.

You will have noticed that the toddy sap before the yeast plants appeared in it was sweet and non-intoxicating; shortly after the yeast has appeared, the toddy loses much of its sweet taste and acquires instead an alcoholic flavour and intoxicating properties. A quantity of gas is evolved and renders the liquid somewhat frothy.

What is the reason of these changes ? They are due to the growth of the yeast and to the fact that yeast is a *ferment* capable of decomposing sugar into alcohol and carbonic acid gas. A ferment is a substance that has the power of setting up definite chemical changes in certain substances with which it comes in contact without itself undergoing chemical change.

That the fermentation of toddy is due to the yeast plant may easily be proved by carefully excluding any yeast plant from the sap when first drawn. Yeast cells and spores are so universally present in the earth, on the palm trees and in the air that to exclude them requires very particular precautions.

Take a number of test-tubes and plug the necks with cotton wool: there are probably many yeast cells or spores in the tubes and wool, so we must ensure their absence or death by heating both the tubes and the cotton to such a high temper-

ature that the yeast or any other animal or vegetable would be killed. This we do by putting them for some hours at intervals of two or three days into a steriliser or stove at a temperature of 110° or 120° C.

We have now to tap the tree, but in doing so we must remember that its outer surface may hold many yeast plants. These we may get rid of by placing a piece of iron raised to a dull red heat against the spot we propose to tap and scorching a few square inches of surface. The knife with which we tap the tree must also be disinfected by boiling or heating for fear there should be some yeast on it. We must select a calm day and see that the leaves above us are not shaken lest some dust containing yeast may fall into our tubes. The tree is then tapped and the sap rapidly collected in the tubes which must be at once plugged with the cotton stoppers.

If all these precautions have been taken, the sap will remain sweet for months and no yeast and no alcohol will be found in it.

If, later, the plug be removed from one of the tubes some yeast plants will almost certainly enter the tube from the air and in a few days we will find the toddy has fermented and contains thousands of yeast cells rapidly growing and multiplying. If we introduce a few yeast plants on the end of a wire and at once re-close the tube the same result will be found.

In actively fermenting toddy, the process of multiplication of the yeast can be easily observed. A small knob appears on the surface of the cell and gradually increases in size till it reaches that of the parent cell. What has happened is that the nucleus has approached the cell-wall, divided

into two, one of which with the surrounding cytoplasm has grown out to form a bud. The cellulose soon forms a partition and the bud may fall off as a separate yeast plant. Frequently the daughter plant gives out a new bud before it separates from the mother cell and in this way chains of yeast cells are produced.

The process of gemmation or budding differs from the binary fission that we have already observed in Amœba, Paramœcium and Spirogyra, only in that the two daughter cells in these latter are from the first equal in size, while in the process of budding the daughter cell or bud is at first much smaller than the mother cell from which it has been derived.

In some circumstances, especially when the yeast is starved by an insufficient supply of food, a second method of multiplication takes place. To observe this make a slope of plaster of Paris or place a piece of unglazed fire-clay in a test-tube. On the surface of this make a streak of yeast from which the toddy has been filtered. Keep the slope thoroughly moist by immersing the lower part in water. The culture should be examined daily after the fourth day when spore formation may be observed. The nucleus and cytoplasm have divided into four new cells, or spores, each surrounded by a wall of cellulose and the whole enclosed in the wall of the original mother cell. These spores have a thick cell-wall and are especially able to withstand desiccation and starvation for long periods.

The yeast or barm which the baker uses for raising bread, and the brewer for brewing beer from malt, and that which causes the juice of the grape to become wine are closely allied to the toddy yeast.

The phenomena of fermentation and the growth of yeast were first elucidated by Pasteur, who found in the juice of the grape, much the same chemical substances as we find in toddy juice, *viz.*, water, sugar, soluble proteid and certain salts. By trying to grow yeast in media from which certain of these constituents were successively removed, he found out what were the essential forms of food without which yeast cannot grow.

He found the following fluid, hence known as Pasteur's solution, was sufficient to grow yeast ; but if any single item, except the sugar, was omitted no growth took place :—

		Per cent.
Water ..	$H_2 O$	83·76
Sugar	$C_6 H_{12} O_6$	15·00
Ammonium Tartrate ..	$(NH_4)2 C4 H4 O_6$.	1·00
Potassium Phosphate	$K3 P O4$ ..	0·20
Calcium Phosphate	$Ca3 (P O4)_2$ ..	0·02
Magnesium Sulphate	Mg. S O4 ..	0·02

To test its powers of growth and nutrition wash some yeast on a filter and then introduce some into each of the following fluids :—

(*a*) Distilled Water.
(*b*) Knop's fluid with C O2 (See page 19).
(*c*) Pasteur's fluid without sugar.
(*d*) Pasteur's fluid with sugar.
(*e*) Pasteur's fluid in which the Ammonium Tartrate is replaced by Peptone.
(*f*) Fresh Toddy juice.

In (*a*) and (*b*) you will find no growth : in (*c*) little growth : in (*d*) good growth : in (*e*) and (*f*) luxuriant growth. You will also find that the presence or absence of sunlight makes little difference in the amount of growth. You will find yeast grow best when the temperature is between 80° and 100° F. and that growth is stopped at very high or very low temperatures.

Analysis shows the yeast plant to contain the elements—Carbon, Hydrogen, Oxygen and Nitrogen with smaller quantities of Sulphur, Phosphorus, Potassium, Calcium and Magnesium. All these elements are to be found in the fluids (*c*), (*d*), (*e*) and (*f*), in which we have seen yeast grow. They are also all present in Knop's fluid that has absorbed Carbonic Acid gas from the atmosphere. We have seen Spirogyra and other green plants thrive in this fluid under the influence of sunlight, but yeast starves because having no chromatophores, it is incapable of assimilating CO_2 as food.

We see that yeast thrives best when it obtains its Nitrogen in the form of organic proteids, but that it can, if necessary, obtain its Carbon and Nitrogen from simple organic, salts like Ammonium Tartrate $(NH_4)_2\ C_4\ H_4\ O_6$. From its mode of nutrition and the fact that its protoplasm is enclosed in a cell-wall of cellulose, it is classified as a plant and not an animal.

Collect in a test-tube some of the gas that is given off during the growth of yeast in toddy juice or Pasteur's fluid. A lighted match plunged into the gas is at once extinguished. If some of the gas be passed through lime water, the latter becomes milky in colour, owing to a precipitate of Calcium Carbonate. The gas is therefore CO_2—not Oxygen

which we have seen given off by Spirogyra and other green plants exposed to sunlight. Most of this C O2 results from the decomposition set up by fermentation in the sugar, which may be expressed by the chemical equation—

$$C_6 H_{12} O_6 = 2\ C_2 H_5 O H + 2C O_2.$$

Sugar = Alcohol + Carbon dioxide.

The quantity of C O2 produced in the process of brewing beer is so great that men and animals have occasionally been suffocated in the vats of breweries.

A very small amount of the C O2 is a result of the metabolic change known as *respiration*, taking place in the yeast plant itself. This process takes place in all plants and animals, but during the day-time green plants assimilate so much C O2 and give off so much oxygen that the process of respiration ceases to be obvious. If, however, a green plant be kept in the dark, so that the process of assimilation is in abeyance, the C O2 given off by its respiration can be readily estimated.

Yeast grows best in the absence of free oxygen. The oxygen required for respiration is derived from compounds like carbohydrates and proteids which the plant breaks up in the process of fermentation.

MUCOR.

If a piece of moist horse-dung or a piece of bread soaked in water be kept under an inverted tumbler, after two or three days you will find it covered with fungi among which will generally be found Mucor, one of the moulds. Mucor appears at first as white cotton-like filaments which soon produce erect, unbranched, pin-like stalks, terminated by rounded heads which though white at first, soon turn black and can be seen with the naked eye.

Examine first with a lens; next pick up with forceps a very small piece of mould; tease it out in water; put on a cover-glass and examine with the one inch objective.

Note (*a*) the *mycelium* consisting of threads or *hyphæ*, which branch repeatedly in the substance of the bread.

(*b*) Certain stouter pin-like hyphæ, growing up into the air, these are called *gonidiophores*, because they bear at their summits the spherical *gonidangia* containing numerous *gonidia*.

Owing to the vast number of Mucor plants present on the bread, the mycelia are usually much intertangled. The student should isolate for study single plants in the following way.

Boil some horse-dung in water, filter the infusion, boil the filtrate for a long time to kill any bacteria or other fungi that may be present. Pinch off a single gonidangium with forceps that have been sterilised in a flame, shake a very few gonidia into a watch-glass of sterilised water. From

this with a sterilised needle transfer still fewer gonidia to another watch-glass of sterilised water to which you have added a few drops of the dung infusion. Leave for a few hours, carefully covered by an inverted tumbler. On examining with a low power you will see the gonidia have swollen to several times their original size.

Fig. 4.

Fig. 5.

Fig. 4.—Gonidium germinating.

Fig. 5.—(*A*) Two hyphæ about to conjugate. (*B*) The gonads, *G* now separated by cell-walls. (*C*) Later stage. (*D*) Zygote. (*E*) The Zygote has given rise to the sporophyte bearing a single sporangium, *F*.

Sterilise some slides in a gas or spirit-lamp flame ; with a sterilised needle take a minute drop from the watch-glass containing the gonidia and spread it in linear streaks on the slides. With the help of a one inch objective remove from each slide all the gonidia except one by wiping off the rest with a sterile rag or blotting paper.

Add a few drops of horse-dung infusion to the slides and leave them for a few hours under a bell-jar or inverted finger bowls. In the course of twenty-four hours, you will find a well-branched mycelium produced.

The hyphæ consist of protoplasm enclosed in a cell-wall of cellulose. With iodine we find no starch, but the protoplasm stains brownish. No nuclei are seen in the fresh specimen, but if we fix with picric acid or alcohol and then stain with safranine, methyl blue or violet, we find many nuclei at irregular intervals. The protoplasm is not divided into cells by septa or partitions in the young Mucor, but in old plants we find several septa of cellulose at irregular distances.

The first step you notice in the culture is that from the gonidium several hyphæ are pushed out which grow rapidly into a much-branched mycelium from which the gonidiophore grows out of the fluid as a thicker hypha. The first stage you notice in the formation of the gonidangium is that the free end of the gonidiophore becomes bulbous and ultimately globular, most of the protoplasm crowding into the swelling. Next a partition of cellulose cuts off the gonidangium from its stalk. In some species the partition bulges into the gonidangium as a *columella*. The gonidangium at first white, becomes dark-coloured, its very thin wall

being often marked by bristling crystals of oxalate of lime. Its protoplasm becomes divided up into a large number of yeastlike cells, the *gonidia*, each being a nucleated piece of protoplasm enclosed in a cellulose cell-wall. A portion of the protoplasm is left over and forms mucilage in which the gonidia are imbedded. If some water be added to the gonidangia when ripe this mucilage swells up, bursts the wall and scatters the gonidia to a considerable distance. The gonidia are blown about by the wind and germinate on reaching a suitable soil. This is the usual method by which Mucor is propagated, but there is also occasionally a sexual method of reproduction.

Two neighbouring hyphæ are seen to approach one another till their walls touch. The tips of these contiguous hyphæ become swollen and filled with granular protoplasm. A cellulose septum cuts off each of these tips, to form gonads, of which the protoplasm and nuclei constitute gametes. The walls of the hyphæ which are in contact disappear, the nuclei of the gametes unite and the two cells form a single zygote, which surrounds itself with a cell-wall covered with black warty projections. In this case we cannot see any distinction between the gametes or say which is male and which female.

The formation of these zygotes occurs at rare intervals but we can encourage their formation by growing Mucor on a thin layer of compressed horse-dung, which is kept moist by water containing about 5 per cent. alcohol. The zygotes appear as little black dots on the dung and can be distinguished with the help of a lens from the gonidangium in that the latter resembles the head of a pin at the

end of the stalk, while the former are either between the conjugating filaments or broken off, the points where they were attached, being marked by clear round spots.

The zygotes are heavier than water and can be isolated by suspending in water the dung on which they have grown and pouring off the floating dirt, mycelium and fluid, while the zygotes remain sunk at the bottom.

The zygotes do not germinate for a month or two, and then, as a rule, give rise to a single hypha at the end of which is borne a sporangium resembling the gonidangium but smaller, and containing a few spores. The spores are oval or globular cells resembling the gonidia. On germinating they give rise to the ordinary branching Mucor.

We have here an irregular alternation of sexual and non-sexual generations. The generation which arises from the zygote gives rise to spores only and is hence called the sporophyte. The spores in turn give rise to a generation which bears the gametes and is hence called the gametophyte. In mosses, ferns and flowering plants there is a regular alternation of these generations, but in Mucor we have a complication in that the generation arising from the spore is only a *potential* gametophyte, that is to say, though it has the power to produce gametes, it, as a rule, suppresses this function and reproduces new generations by means of gonidia which in all respects resemble spores except that they are borne on a gametophyte.

It will be noticed that Mucor contains neither chlorophyll nor chromatophores. Its manner of nutrition is practically the same as that of yeast, but you will have noticed that Mucor grows on the *surface* of the medium sending

downwards hyphæ into its substance, and other specialised hyphæ, the gonidiophores, upwards into the air.

If Mucor be grown completely submerged in fluid, a peculiar change comes over the plant. The hyphæ become beaded like a necklace, septa are formed and each bead becomes a separate cell, the whole resembling a chain of yeast plants not only in appearance but also in its power of setting up alcoholic fermentation. Some gonidia should be sown on a thin layer of dung infusion or Pasteur's fluid with peptone, spread on a slide and covered with a large cover-glass to see the formation of these "Mucor Yeasts."

Under ordinary circumstances Mucor obtains the oxygen required for its respiration from the atmosphere. When, however, it lives submerged in a fluid in the form of Mucor Yeast its respiration is carried on in the same way as in the Yeast plant.

BACTERIA.

Pour some hot water over a bunch of hay in a basin and allow to stand for about an hour. Then filter through paper or linen. Place some of the filtrate in a series of test-tubes or flasks. Plug the necks with cotton. Boil two of the tubes for five minutes. Remove the plug from one of these two.

In a day or two observe the fluid in—

(*a*) the unboiled tubes has become turbid,

(*b*) the boiled and plugged tube remains clear,

(*c*) the tube which has been boiled but left unplugged has become turbid, but probably is not as turbid as (*a*).

On examination with the highest power of your microscope you find the turbidity is due to the presence of millions of minute rod-shaped plants called Bacteria. (Gr. rods.)

Almost all are seen oscillating but this movement is not an indication of life, but only the " Brownian movement " common to most minute particles, animate or inanimate, suspended in fluid. Similar movements will be seen in finely powdered gamboge suspended in a drop of water. You can ensure the absence of life by first heating the gamboge far above boiling point.

Many Bacteria exhibit not only Brownian oscillation but also true motile and locomotive power, and can be seen swimming in the field of the microscope. The movement is due to the presence of minute flagella which can only be demonstrated by complicated methods of staining too difficult for the elementary student.

The reason there are no Bacteria in tube (*b*) is that by boiling you have killed all those at first present and so prevented their multiplication.

You also killed all those present in tube (*c*) but as bacteria are almost universally present, floating in dusty air, a few have got into the unplugged tube and multiplied with extraordinary rapidity. (See page 6.)

The Bacteria are all extremely minute organisms. The smallest are scarcely visible with the highest power of the microscope. Special oil-immersion lenses are necessary for their study. As these are not generally at the disposal of the student of elementary biology, he cannot do much practical study. It will suffice for him at this stage to understand the biological position and general characters of the Bacteria.

Bacteria are by most biologists regarded as unicellular plants—not animals. Haeckel included them in his Protista (p. 384).

Like other plants each bacterial cell possesses a cell-wall, in which, however, cellulose is only occasionally found. The cell-wall generally contains a nitrogenous substance allied to chitin.

Their protoplasm is not clearly differentiated into cytoplasm and nucleus, as the chromatin, which in ordinary cells is accumulated in the nucleus, is scattered promiscuously in the protoplasm of the bacteria.

All Bacteria multiply by simple transverse fission, hence the name sometimes given, Schizomycetes. (Gr. Fission-Fungi.) Some of them in addition multiply by spore-formation. The protoplasm is seen to collect at a certain spot,

generally the centre, more rarely the end of the rod where it forms a round or oval refractive dot which does not stain with the ordinary aniline dyes. The cell-wall ultimately breaks up and sets free these refractile dots as the spores. They have extraordinary powers of resistance and can withstand extremes of drought, cold and heat without perishing. For instance, the spore of the bacillus that causes tetanus can survive a temperature of over 105° C, and withstand boiling for five minutes.

If the experiment described at the beginning of this chapter has been a failure and the boiled and plugged fluid has become turbid this is due to the presence and survival of some spores.

In general the mode of nutrition of Bacteria agrees with that of most Fungi. (See Yeast and Mucor.)

Almost all are devoid of chlorophyll and therefore cannot construct carbohydrates from carbon dioxide and water. They cannot make use of inorganic nitrates to form nitrogenous substances like proteids. They require ready-made carbohydrates and proteids as food. Many flourish most luxuriantly on dead animal and vegetable matter in which they find proteid food ready formed, and in which their growth sets up those physical and chemical changes which we know as *decomposition* and *fermentation*. These plants which live on decomposing organic matter are called *Saprophytes*. (Gr. *Sapros*, rotten ; *phyton*, plant.)

Others can only live or flourish in the tissues of living animals or plants ; such are called *parasites*. Many of these Bacteria give rise to infective diseases such as Plague, Cholera, Typhoid, Consumption, Blood-poisoning, Diphtheria, Leprosy,

Pneumonia, etc., by their multiplication in the bodies of their hosts, while their fermentative actions produce the poisons known as *toxins* which circulate in the blood.

Some known as *ærobic* bacteria flourish in the presence of air, others, like the tetanus bacillus, can only multiply in the absence of oxygen and are therefore called *anærobic*.

From their general mode of nutrition, most biologists formerly believed that the Bacteria and all Fungi are degenerate descendants of former chlorophyll-containing plants, as it seems obvious that the first organisms to appear on the Earth cannot have been animals or Fungi that require as food ready-made proteid. It was generally believed that the Bacteria were originally chlorophyll-bearing cells which, having for innumerable generations obtained their food from ready-made proteid in their parasitic or saprophytic mode of life, have become degenerate and ultimately lost their chlorophyll and therewith the power of obtaining their food from inorganic constituents.

Recently however evidence has been adduced that certain Bacteria live free in the soil and have the power of obtaining their food entirely from inorganic substances although they have no chlorophyll. These Bacteria are of great value in agriculture as some have the power of forming nitrites out of salts of ammonium, and others the power of turning nitrites into nitrates—a valuable item of food for the higher plants.

In the light of this knowledge we must admit that it is at least possible that the first organisms to inhabit the Earth may have been similar to these "Nitrifying Bacteria" and not necessarily chlorophyll-containing plants.

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With a glass rod remove a drop of the turbid fluid and smear it on the surface of a cover glass. When it has dried, hold the cover, smear upwards, between your finger and thumb and pass it four or five times through a flame. The heat will fix the Bacteria to the glass. Stain for a few seconds with fuchsine or methylene blue ; wash well with water ; dry gently over the flame, after blotting off the excess water ; mount direct in balsam on a slide.

With the highest power of your microscope, the Bacteria in the hay infusion are now seen to be long deeply-stained rods, fairly uniform in diameter (about 1.5μ.) but varying greatly in length. The individual bacilli may average 6μ. but many are united end to end to form long strings.

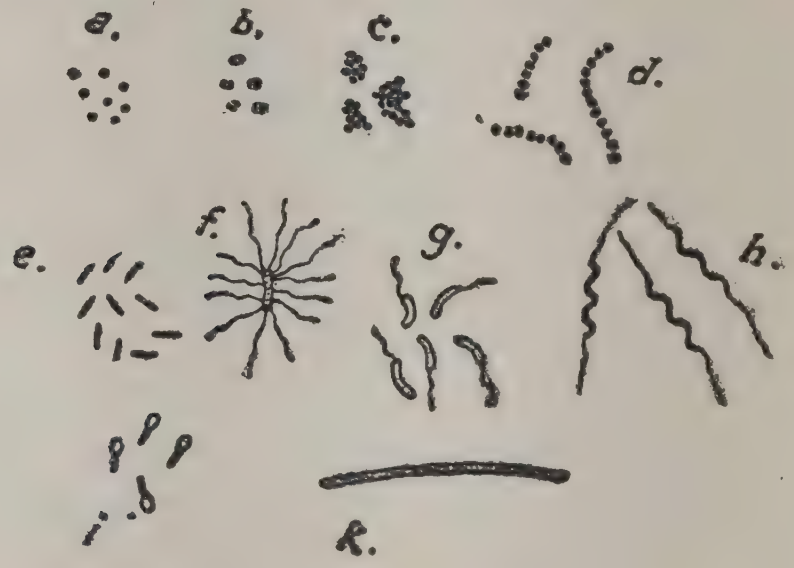

Fig. 6.—*Different forms of Bacteria—*

A.—Scattered Cocci.
B.—Cocci in pairs.
C.—Cocci in clusters.
D.—Cocci in chains.
E.—Bacilli.
F.—Bacillus with flagella.
G.—Vibrio.
H.—Spirilla.
I.—Bacillus with terminal spore.
K.—Chain of bacilli with central spores.

The various genera of the class Bacteria are distinguished by their shape. Small oval or globular forms are known as *Micrococci*, (Gr. *micros*, small ; *kokkos*, berry). Most of them are from 1μ. to 3μ. in diameter. Boils, Gonorrhœa, many Abscesses and forms of Blood-Poisoning are due to the presence of micrococci in the tissues. The name *Bacillus* (Lat. a little rod) is given to straight rod-shaped Bacteria. The diseases, Anthrax, Consumption, Leprosy, Typhoid and Tetanus are caused by specific bacilli entering the human body.

The term Bacteria is often used to indicate the whole class of Fission Fungi, but is also used in a restricted sense to indicate a genus of rods shorter than the bacilli. The limit is not clearly marked, but the generic name *Bacterium* is usually restricted to an organism not more than twice as long as it is broad.

Vibrio is a curved bacillus. If after fission the individual vibriones do not separate from one another, they may resemble spirilla. Cholera is caused by the "Comma vibrio."

Spirillum, as its name indicates, is a spiral or cork-screw-shaped organism. Large specimens can often be seen in tank water and generally in the white "fur" that collects on the human teeth and in an infusion made of powdered *dal* or gram seeds.

The spirilla are large, refractile and draw attention to their presence by their active rotary or oscillatory movements.

The so-called spirochaetes which give rise to Relapsing Fever and Syphilis are probably not Bacteria but species of Protozoan animals.

The student will note that many diseases of both animals and plants are caused by parasitic organisms. A vulgar error is to include all the smaller or microscopic parasites under the head "Bacteria." This is incorrect, though many of the minute organisms causing disease, such as those mentioned in the preceding paragraphs are Bacteria, *i.e.*, *vegetable* parasites, many others are Protozoa, one-celled *animal* parasites. Examples of protozoa causing diseases are the parasites of Malaria, Syphilis, Kala-Azar, Sleeping Sickness and Delhi Sore. The term "Microbe" (Gr. *Micros*, small, *bios*, life) may accurately be used to indicate all the unicellular animals and plants, including the "germs" of disease.

THE HYDRA OF BOMBAY.

H. pentactinella.

Collect a quantity of floating water weeds, such as Water-Lillies, Lemnanthemum, Azolla and Duckweed from a tank or pond in which there is clean water all the year round.* In the cold weather a little of the mud from the bottom should also be collected, and the whole placed with plenty of fresh water in a large glass vessel, in a room not exposed to direct sunshine. Cover the top and sides of the vessel with a cloth or with brown paper leaving only a small window at one side of the vessel near the surface of the water.

Next day examine the exposed part of the vessel and you will most probably find a few small yellowish white gelatinous-looking threads, from one to twelve millimetres in length, attached to the inner surface of the glass. With the aid of a lens you will see that these bodies bear at their free end five finer threads in continual slow movement.

This is a little animal known as *Hydra*. Further examination will show that it is attached by a basal *sucker* to the glass, and that the animal is able alternately to elongate and contract the body and also the five thinner processes or *tentacles*. At one moment it may exceed half an inch in length and the next moment, if irritated by touching with a needle, will contract so as to resemble a globule of jelly in which the tentacles are reduced to mere papillæ. In cold

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* The tank near the elephant house in the Victoria Gardens is almost certain to contain specimens.

weather the room should be kept somewhat warm. As at this season *Hydra* does not show such a decided preference for light or the glass surface, some days may elapse before any come to the window.

Place one of these animals in a watch-glass or on a hollow slide with sufficient water to cover it and examine with a low power of the microscope.

The body is a cylinder or tube composed of an outer layer of clear cells and an inner layer of large yellowish brown cells. The body in fact resembles a test-tube in shape, there being no aperture at the fixed or sucker end. The tentacles are inserted near, but not quite at the free end of the body. Above their insertion is a slight conical process, the *hypostome**, in the centre of which may be seen the mouth, which serves not only for an entrance to the food, but also as an anus or aperture of exit for the fæces.

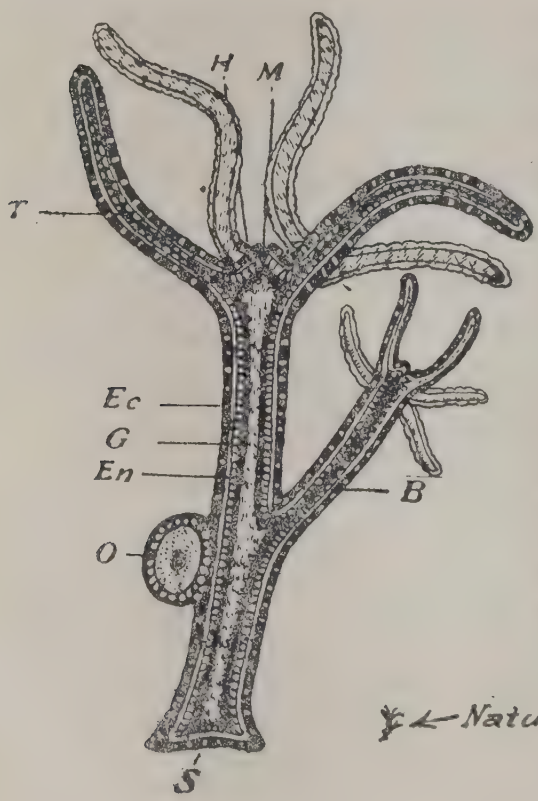

Fig. 7.

The *enteron*† or digestive cavity is continued into the hollow tentacles

* Gr. *hypo* below, *stoma*, mouth.

† Gr. gut.

which in the vast majority of Bombay Hydras are five in number. Of 549 specimens consecutively examined. 14 had six tentacles, 9 had four, 526 had five tentacles. Variation in the number of tentacles is not an indication of difference in species, as a six-tentacled bud has been seen growing from a five-tentacled parent.

Some small animals, such as water-fleas, should be placed on the slide with Hydra. These little crustaceans are very vivacious, darting hither and thither almost continually, but should one of them come in contact with the tenctacles of Hydra, it will suddenly come to a standstill as if struck with paralysis. If the Hydra be hungry, the stunned water-flea is gathered into the mouth by the tentacles and passed into the enteron, where it may be seen causing a bulge as does a rat swallowed by a snake. This stunning of the little animal is due to certain stinging threads on the outer surface of the Hydra. You can realise the effect by touching with your finger a jelly-fish, an animal closely related to Hydra,

To examine with the higher powers of the microscope a cover-glass should be placed over a Hydra on a hollowed slide. If you have no hollowed slide, a cell can be made by placing a thick cover-glass on each side of the Hydra, and a third over the animal with the edges resting on the other covers so as not to cause undue pressure.

The tentacles and body will be seen covered with wart-like knobs, which careful focussing will show are due to collections of cells containing highly refractile oval sacs the *stinging capsules* or *nematocysts*.* When the tentacles

* Gr. *nema*, thread ; *kystos*, a bladder.

are fully extended, spaces are seen free of stinging cells, when moderately contracted the tentacles are fairly uniform in diameter. When the Bombay animal is fully extended, the tentacles seldom exceed the body in length.

In the Hydras of Europe they may be three or more times, and in that of Bengal, according to Annandale, as much as six times the length of the body.

Some Hydras should be killed by pouring a little 1 per cent. osmic acid solution over them while fully extended. The ordinary fixing solutions, such as methylated spirit, picric acid, Perenyi's or Muller's fluid, if used should be poured on in a boiling condition, so as to kill the animal at once before it has time to contract. After fixing, washing and staining with carmine, picrocarmine or eosine and hæmatoxylin, they should be imbedded in paraffin, and both transverse and longitudinal sections made.

A comparison of the whole animal with these sections will show that body and tentacles are hollow tubes, their cavities continuous and their walls composed of two layers, an outer of smaller transparent cells, an inner of larger yellowish cells. The outer is called the *ectoderm*,* the inner the *endoderm**. Between them is a very thin *supporting lamella*, not of cells but of a jelly-like substance called the *gloea*,† which in closely related animals is so thick and obvious that they are popularly called "Jelly-fish," By some authors this layer is termed the *mesogloea*, Greek for "middle

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* Gr. *ecto*. outer, *endo*, inner, *derma*, skin.

† Gr. *gloia*, jelly, glue.

jelly," but as there is no outer or inner jelly, the shorter name, gloea, is preferable, especially as students are liable to confound it with the *mesoblast*, or middle *cell*-layer of higher animals. The important fact which the student should grasp is that this layer is not made of cells but is a jelly *secreted* by the cells of the cell-layers. Hence Hydra, Jelly-fishes and their allies are sometimes called *Diploblastic** that is composed of two cell-layers, to contrast them with the *Triploblastic** animals,—all the higher Metazoa composed of three cell layers, epiblast, mesoblast, and hypoblast, or ectoderm mesoderm and endoderm.

Another Hydra should be arranged on a slide under a cover-glass, a little safranine, methyl violet, or 0·5 per cent. acetic acid coloured with fuchsin run in while the effect is watched by as high a power of the microscope as convenient. From the little projections on the surface slender threads are seen to be suddenly shot out from the nematocysts. These are the stinging threads.

The animal will probably break up into its individual cells or the process may be assisted by teasing with needles. When sufficiently stained the surplus fluid may be removed by blotting paper and the specimen irrigated with a little water.

An examination of these preparations will show that the cells of the outer layer are of three kinds :—

1. Large conical cells with their bases facing outwards, their narrow ends inward. At their inner ends may be seen long *muscle processes* which are

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* Greek, *diploos*, two-fold, double, *triploos*, triple, three-fold.

arranged parallel with the length of the animal. The shortening of the tentacles or body is due to their contraction. Fig. 8 m.p.

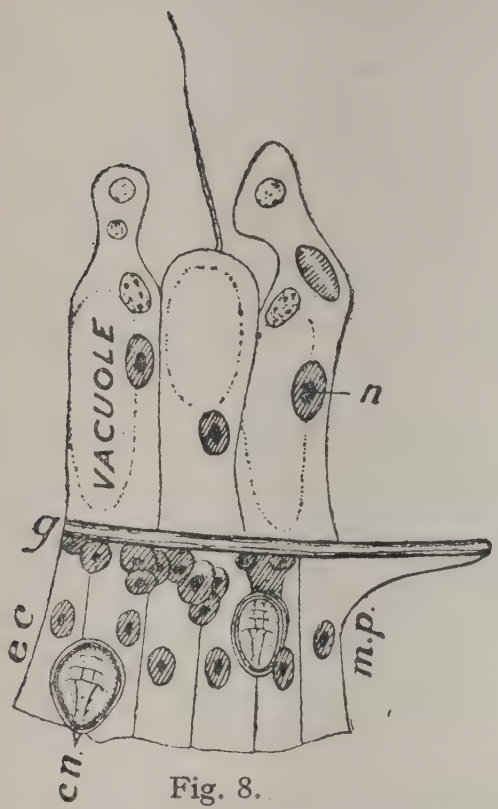

Fig. 8.

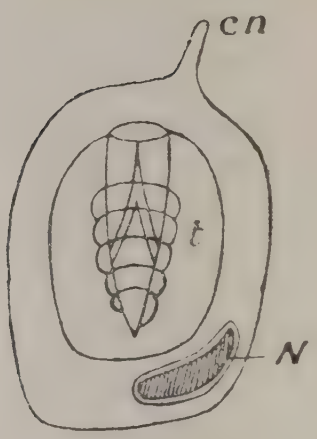

Fig. 9.

Fig. 8. cn.=cnidocil, ec.=ectoderm, g.=gloea, m. p.=muscle process, n.=endoderm.
Fig. 9. A cnidoblast. cn.=cnidocil, N.=nucleus, t.=nematocyst.

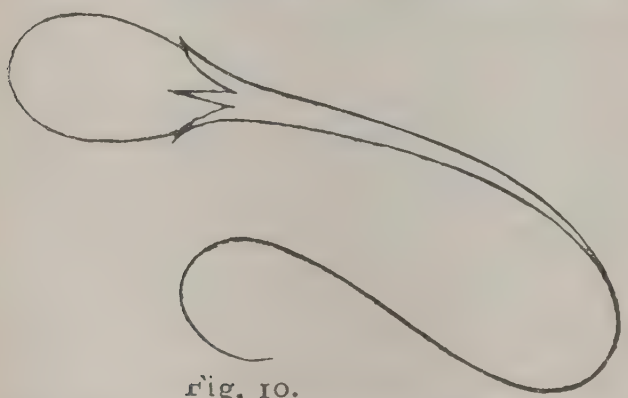

Fig. 10.

Fig. 11.

Fig. 10. Large stinging thread. Fig. 11, Small stinging thread.

(2) In the intervals between the apices of these cells will be seen smaller, more rounded, granular and deeply stained *interstitial cells.*

(3) Certain of these interstitial cells develop into *stinging cells* or *cnidoblasts** that make their way to the surface and in addition to the nucleus contain a *thread capsule* or *nematocyst*, which has been likened to a glove with a single long-pointed finger; the finger turned outside in and coiled up in the palmar portion of the glove. On the outer surface of the thread cell can be seen a short hair-like projection, the *trigger* or *cnidocil.* The interior of the cyst is filled with fluid under considerable pressure. When a suitable stimulus irritates the sensitive trigger the cyst is compressed and the stinging thread forcibly everted.

The nematocysts are of two kinds :—

(1) A smaller containing a short thread folded in loops. When discharged the thread ends bluntly and often resembles a screw in outline owing to a spiral coil. The whole stains deeply and uniformly. (Fig. 11.)

(2) The large nematocysts containing a thread about ten times the length of the former, coiled round its base; when everted the thread is seen to be much thinner, ending in a fine lash, and bearing three main barbs at its conical base. The lash and barbs stain deeply, the flask-like base feebly, with aniline dyes. (Fig. 10.)

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* Gr. *knide* a nettle, *blaste* a bud, development, hence applied to cells or tissues in or by which any structure originates.

It is probable that the action of the stings is not merely mechanical, but that the fluid of the cyst also produces a poisonous effect on the animal struck. The threads when discharged remain embedded in the body of the prey, new nematocysts being developed to take the place of those used up.

The stinging cells are found not only on the tentacles but also on the body. They become fewer as the sucker end is approached. It will be noticed that the ectoderm cells near the sucker are much more granular than those elsewhere owing to an adhesive secretion by which the animal fixes itself to other bodies. The teased and stained specimens may be preserved by rapidly drying the slide by waving it in the air, and when apparently dry, heating the slide *gently* over a flame. Canada Balsam and cover-glass may then be dropped on.

Certain small cells with spidery processes in connection with the stinging cells are supposed to be nerve cells through the agency of which Hydra can voluntarily discharge the threads. *Paramoecia* and other infusorians can be seen to creep over the tentacles without causing rupture of the stinging capsules, from which we conclude Hydra is able to distinguish different kinds of stimuli and to select its prey.

The endoderm cells are much larger than those of the ectoderm. A small piece of a living Hydra should be examined under a cover-glass, when it will be noted the endoderm cells are actively amœboid, putting out or withdrawing long pseudopods. Some of the cells may be seen to put out one, two or three long flagella. These flagella are not

seen in stained specimens as they are withdrawn in the act of death. The endoderm cells contain very large vacuoles. Many of those near the hypostome are long, narrow and much more granular than those elsewhere. They are of a glandular nature, probably secreting a digestive fluid.

It should be noted that digestion in this animal takes place in two ways (*a*) by the digestive fluids turning the food into soluble substances which enter the cells by osmosis; (*b*) by the amœboid endoderm cells engulfing solid particles.

Some of the endoderm cells exhibit muscle processes like those of the ectoderm but they are shorter and arranged in a direction transverse to the length of the body. Their contraction will therefore narrow the lumen and lengthen the body.

REPRODUCTION.

In an equable climate like that of Bombay Hydra multiplies all the year by *budding*, provided it receives plenty of food. A little knob or projection appears on the side of the body, and gradually lengthens into a little tubular process, the cavity of which is continuous with the enteron of its parent. Tentacles and a mouth then appear at its distal end, and finally the connection with the parent body is severed by an ingrowth of the ectoderm. In the Bombay species of Hydra it should be noted that all the tentacles appear simultaneously. Sometimes we find a number of buds in different stages of development attached to the parent body, giving the appearance of a colonial organism.

If a Hydra be cut in two, each part is capable of regenerating into a complete Hydra.

Both these methods are *asexual*. There is also a *sexual* process of reproduction. If food becomes scarce, the temperature too cold or too hot, or if the tank or pond in which Hydra lives, begins to dry up, sexual reproductive organs develop. In Bombay these *gonads* are most common at the beginning of the dry season, October and November. One or more, or as many as five testes may then appear, as little breast-shaped outgrowths of the ectoderm in the distal half of the body. From the interstitial cells in these outgrowths *spermatozoa* with oval heads and vibratile tails are developed.

In most species of Hydra both testes and ovaries develop on the same animal, which is therefore *hermaphrodite* but the testes in such cases have always discharged their sperm cells by rupture of their walls before the ovum is matured. In this way self-fertilisation is prevented. In Bombay we have never yet seen testes and ovaries develop on the same Hydra, so that as far as observation has gone, this species is not hermaphrodite.

The ovary is larger and more rounded than the testis usually extending over about half the circumference of the body, in a situation nearer the sucker than that in which testes are found. Like the testis, it is formed from the interstitial cells of the ectoderm. A number of these cells form the wall of the ovary. Those in the centre become potential ova, but one of them rapidly enlarges at the expense of the others, till finally we have a single large egg-cell or ovum left. If you find an egg-cell in this condition, rupture the ovary by gentle pressure, and examine under a cover-glass with the higher power.

You will find the ovum is a very large amœboid cell putting out irregular pseudopods. In addition to a clear nucleus, the *germinal vesicle*, with a number of nucleoli or *germinal spots*, it contains many large *yolk granules*.

The ovum mature in the ordinary manner by successively casting out two polar bodies. The superficial cells of the ovary then rupture, allowing the spermatozoon to have access to the egg-cell and fertilise it.

This *zygote** or fertilised ovum, then divides into a number of cells to form a *mulberry*-mass or *morula*,† the outer cells of which form a hard, tough, water-proof shell, inside which the embryo can remain dormant throughout the cold and dry season. When the rains again set in, or the season becomes otherwise favourable, the embryo develops into a young Hydra.

You will note how Hydra resembles the *gastrula* stage of higher animals consisting of two cell-layers, an outer ectoderm and an inner endoderm, resembling the epiblast and hypoblast respectively, the mouth suggesting the blastopore, the enteron, the archenteron. The development of Hydra is however exceptional. The morula becomes hollowed out into a blastula. The cells become differentiated into an outer layer, the ectoderm, and an inner *solid* mass, the endoderm. Later a cavity, the enteron forms, by the endoderm cells separating from one another. Still later a mouth is formed. Hydra therefore differs in its mode of formation from the gastrula in that the *endoderm is not formed by an invagination of the blastula, the mouth therefore is not a blastopore but an opening formed secondarily.*

* Gr. *Zygotos* mated, married. † Lat. Mulberry.

PERICHÆTA POSTHUMA, A COMMON EARTHWORM IN INDIA.

Syn. *Pheretima postuma.*

Earthworms are to be found throughout almost the whole habitable surface of the globe. A certain amount of moisture and warmth being essential, arid sandy deserts, the ice-bound regions near the poles and summits of lofty mountains are the only places where we fail to find some representatives of the order.

In the cold and dry seasons which we experience in most parts of India, many species withdraw deep in the soil to burrows which they line with the slimy secretions of the body which dry into an almost water-tight covering that prevents the excessive evaporation which would prove fatal if the worm were exposed to our dry atmosphere.

The name Earthworm is fairly indicative of the animal's habitat and habits. Most burrow in the soil, living on decaying organic matter which they swallow with a large admixture of earth. The undigested residue or fæces is passed usually on the surface of the earth in the form of " casts." The size and number of these casts is very great, and in Bengal in particular they are a great source of annoyance to the *mali*, who during the rains finds his well-kept lawn each morning disfigured with large casts which he wrathfully describes as the fæces of a *Shaitan*.

Darwin estimated that the quantity of fæces brought to the surface by worms would amount in five years to a layer one inch thick over the whole surface of England.

The services thus rendered to the cultivator by Earthworms consist in a continual ploughing of the soil and bringing finely divided manure from the depths to the surface.

The Earthworm is nocturnal in its habits. It has no eyes and needs no light to guide it in the pursuit of food or a partner in its amours, so during the daytime it retires to its burrow.

The Earthworm is hermaphrodite, but the ova are probably never fertilized by the sperm of the same individual.

Select a large and stout worm. Draw it gently through your fingers from before backwards. You find it is smooth and "slippery as a worm." Draw it in the opposite direction, *i.e.*, from "tail" to "head," there is a distinct roughness which, on examination with a lens, you find is due to a number of bristles (Latin) *setæ* or (Greek) *chetæ*. These are functional as aids to locomotion, preventing the animal slipping backward when it progresses by alternate contraction and elongation of its body.

Select a worm with continuous rings of setæ round the anterior segments excepting the first. In Bombay this will probably be a *Perichæta*. Examine the ventral surface of the eighteenth somite. If you find a median depression, in which careful examination will show two openings placed close together, the worm is probably *Perionyx*. If the setæ be few in number—only four pairs on each segment—the worm does not belong to the Perichæte family.

In England all the native worms possess only eight setæ on each segment.

Should you find a worm with rings of setæ not quite continuous, there being ventral or dorsal gaps, the worm is a *Megascolex* (Gr. *megas*, great, *skolex*, worm), of which there is a very large species in Ceylon and India. They measure up to three feet in length and are therefore excellent for dissection. Unfortunately they are rare in Bombay, probably being only accidentally imported, so we must take a more common species for study.

The genus *Perichæta* can be recognised externally by the continuous rings of setæ, the pair of openings on the eighteenth segment, and a girdle encircling the fourteenth, fifteenth and sixteenth somites only.

One of the commonest species in Bombay is *P. posthuma*. Its male pores are raised on prominent nipples or papillæ; on the segments in front of and behind these pores we also find a prominent pair of papillæ, so that this species can easily be distinguished by these three pairs of prominences on the under surface of the 17th, 18th and 19th segments.

As this species can be so readily distinguished and is one of the most common in India, the details of the following description will specially apply to it.

Attention will be drawn here and there to the anatomy of other species, and even of other genera, so that if the student is unable to obtain this particular worm he can nevertheless gather the main facts in the structure of allied forms.

For practical dissection, therefore, choose, if you can, an Earthworm with continuous rings of setæ, with a girdle limited to segments XIV, XV and XVI, having setæ on its ventral sur-

face, with six papillæ in pairs on segments XVII, XVIII, and XIX.

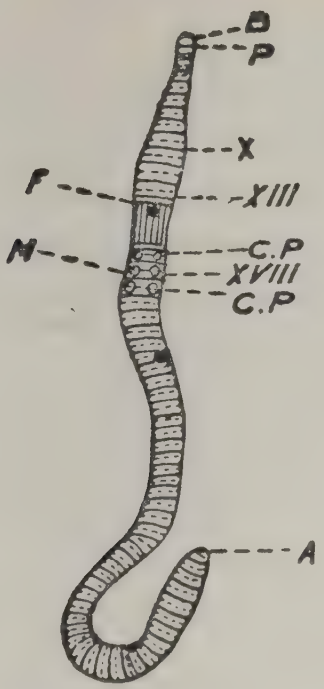


Fig. 12.
Perichæta postuma.
B. Buccal cavity.
C. P. Copulatory papilla.
M. Male pore.
F. Female pore.
A. Anus.
P. Peristoma.

EXTERNAL APPEARANCES.

The worm is about three inches long (50 to 120 mm.) about 5 mm. in diameter, cylindrical in shape, except that the posterior end is rounded off and the anterior end tapers like the end of a cigar. There is no trace of limbs or lateral head appendages, and no division of the body into head, neck, thorax and abdomen. Externally it is marked by ring-like grooves which divide the body into a number of segments closely resembling one another. Dissection will show you that this segmentation characterises the internal organs also, the nervous, alimentary, excretory, circulatory and to a less extent, the reproductive organs. Each segment is a copy of the segments in front of and behind it.

In fact, if you cut up the posterior two-thirds of the body into its individual segments, it would be impossible for the most expert zoologist to place them in order, each one being so close a repetition of the same plan. These segments are technically known as *metameres* or *somites* (Gr. *meta*, behind, *meros*, a part, *soma*, body). Such somites are said to be *serially homologous* with one another, and such an animal is said to be *metamerically* segmented.

If you count the somites you will find these are about 120 to 140 in number.

Though the posterior region of the body is cylindrical, the animal has the power of flattening it from above downwards to a considerable extent, as you will find if you attempt to draw a worm from its burrow. By thus increasing the width of the body a " purchase" is obtained on the walls of the burrow.

Observe the manner in which the animal moves. Most worms crawl by a characteristic wriggling " worm-like " movement, but *Perichæta* and some species of *Perionyx* in particular, are very agile and move with great rapidity using their protrusible buccal cavity as a sucker, so that they can " loop " along after the manner of a leech.

Observe the most anterior segment which, from the fact that it surrounds the mouth, is called the *peristome* (Gr. *peri* around, *stoma*, mouth). It bears no setæ and reaches further forward on the dorsal than on the ventral aspect. In the dead worm you must not mistake for the peristome the everted buccal cavity which the worm can protrude to a very considerable distance, at least 2 mm. The everted buccal lining is wrinkled radially resembling a diminutive human anus. In

some other Earthworms there is a small *prostomium* overhanging the mouth like an upper lip and dovetailing behind to a variable extent into the peristome. It cannot be recognised in our species.

Note and count the bristles on the second segment. Observe that they are continuous, with no dorsal or ventral gap in any *Perichæta* (or *Perionyx*) and that there is a distinct ridge where the bristles are inserted.

In an adult worm there is seen on segments XIV—XVI an enlargement caused by a thickening of the skin and a development of glands which assist in forming the cocoon. In the Perichæte worms it forms a complete *girdle* (in Latin *cingulum*) round these segments and is therefore appropriately called by either of these names. Its prominence varies with the sexual activity of the worm. The colour is a different shade to the rest of the body, and usually becomes white in specimens preserved in spirit.

In many other worms this thickening does not extend all round, being deficient or absent on the ventral surface. It then resembles a little saddle on the dorsum of the worm and is called the *clitellum* (Latin *clitellae*, a pack-saddle). The position and extent of this organ vary in different species. In *Perionyx* they are in some species the same as that described above, segments XIV to XVI, but more often they begin a segment earlier and may extend even to the XIX segment. In the Indian species of *Megascolex* the cingulum begins on segment XIII and extends to XVIII most commonly, but in the giant worm of Ceylon *M. cæruleus*, it reaches from XIII to XXI. While three segments of girdle is the rule in *Perichæta*, in *Megascolex* $3+x$ may be laid down as a diagnostic feature.

In the *Lumbricidæ*, the common worms of Europe, the clitellum is placed very far back, from XXX to XXXVI or thereabouts, therefore well behind the male pores, not in front of them as in *Perichæta*.

Note also that in this species the rows of setæ on the three clitellar segments are limited to the ventral surface, being absent on the dorsum and sides. In some specimens the setæ are ill developed or even absent on the girdle segments.

Note the colour of the worm ; dark-brown with perhaps a tinge of purple above ; paler, perhaps yellowish-brown, on the ventral surface. A narrow dark streak in the mid-dorsal line indicates the dorsal blood vessel. About segments XVI to XX two lateral white organs, the *spermiducal glands*, generally show through the integument.

OPENINGS OF THE BODY.

The mouth has already been seen at the extreme anterior end leading into the protrusible buccal cavity. The anus is a vertical oval aperture, also terminal, on the posterior aspect of the last segment.

The openings of the sperm ducts or vasa deferentia are readily recognised on a pair of widely separated papillæ on the ventral surface of the eighteenth segment.

On segments XVII and XIX are seen paired papillæ in front of and behind the male openings. In the spirit-preserved specimen, depressions, looking more definite openings than the male pores, are seen on their summits. These do not open into the body cavity, but are of the nature of copulatory suckers formed by a depression of the epiderm lined by elongated pear-shaped epithelial cells, of a glandular nature. The glands are seen internally as rounded white elevations.

In *Perichæta* the oviducts open ventrally by a common median pore on the fourteenth segment at the anterior margin of the girdle.

Four pairs of openings, those of the spermathecæ, can be seen on the ventral surface of segments VI, VII, VIII and IX. They are very small and are best seen after drying the worm with blotting paper and then gently squeezing with the fingers. Small beads of moisture will exude and indicate the position of the pores.

In other species of *Perichæta* and in other genera the number of spermathecæ, and therefore of openings, varies. Other *Perichætæ* may have only one pair or as many as five. The openings may be furnished with papillæ.

In *Perionyx* the apertures are placed very close together near the middle line, and both pairs may open on the same, the eighth segment.

The female openings are double on the 14th segment in *Perionyx*, *Megascolex* and most Indian worms as well as in all the European family *Lumbricidæ*.

The *dorsal pores* are minute openings into the cœlom between the segments in the mid-dorsal line. They are best seen in specimens preserved in spirit, but can also be seen with a lens on squeezing the worm after drying as above advised.

They are simply holes through the layers of the body-wall and have no special lining of cells. They are absent from the first twelve segments, the first being found between segments XII and XIII.

The *openings of the nephridia* or excretory organs are very numerous in each segment in all *Perichætæ* and too small to be seen except in sections under the microscope.

DISSECTION.

The worm is best killed by dropping into methylated spirit for a few minutes.

Stretch it firmly, but gently, with the fingers. Pass flagged or coloured pins through the body-wall at the sides of segments V, XV and XXX, taking care not to injure the internal organs. With other pins fix the worm ventral side downwards, in an extended position to a sheet of cork or soft wood weighted with sheet lead. Dissect in a dish under water.

Using coloured or flagged pins in definite segments will be a guide to the situation of the organs and will save much time and trouble in counting. They may be placed in any segment, provided a note is made of its number, preferably on a skeleton chart. With small fine-pointed scissors slit up the body-wall throughout its length close to the mid-dorsal line, avoiding the dorsal vessel and taking care not to open the alimentary canal. The latter accident will be readily recognised by the escape of earthy food ; should it happen, begin your incision more carefully at another point.

A sketch of all the organs should be made on the skeleton chart supplied.

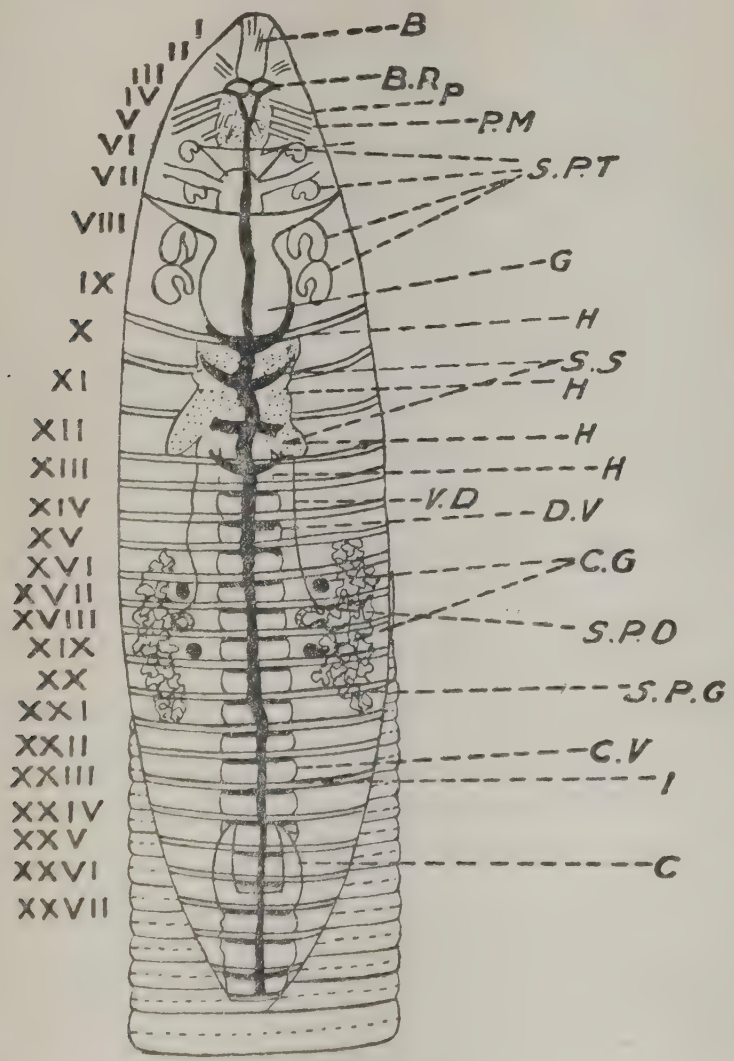


Fig. 13.

Fig. 13.—*Perichæta postuma*. *Anterior segments laid open*—B. Buccal cavity. Br. Brain. C. Cœcum. C. G. Copulatory gland. C. V. Commissural vessel. D. V. Dorsal vessel. G. Gizzard. H. Heart. I. Intestine. P. Pharynx. S. Septum. S.P.G. Spermiducal gland. S.P.D. Its duct. S.P.T. Spermatheca. S.S, Sperm sac. V.D. Vas deferens.

THE CŒLOM.

You have now laid open the body-cavity or *cœlom* (Gr. *koiloma*, a hollow), a large space in which the alimentary and other viscera are contained. It is divided into a number of compartments corresponding to the somites by transverse septa (Lat. *septum*, a partition). Above the nerve-cord the septa are incomplete and allow the cœlomic chambers to communicate with one another.

The anterior septa are incomplete, their place being taken by numerous muscles radiating to the body-wall from the pharynx. The septa behind segments V, VI, VII and IX are much thickened and muscular. There is none between VIII and IX, the segments occupied by the gizzard.

Posteriorly they are thin and membranous. Both surfaces of the septa as well as the inner and outer walls of the cœlom are lined by the cœlomic epithelium or *peritoneum*.

These lining cells are for the most part flat, being of the character known as tessellated, but on some parts of the gut the epithelial cells are large, globular and loaded with granules of pigment, which give them the name of *yellow cells*. They probably excrete material into the cœlom whence it is removed by the nephridia.

The cœlom communicates with the exterior through the dorsal pores, the genital ducts and the nephridia.

The whole worm resembles two tubes placed one inside the other, and continuous at both oral and anal ends. The inner tube is separated from the outer by a wide cœlomic space, and is maintained in position by the numerous transverse septa or mesenteries.

DEVELOPMENT OF THE CŒLOM.

In the embryo between the *hypoblast* or lining of the primitive gut, and the *epiblast* or primitive epiderm which are at first in contact, a third layer, the *mesoblast* (Gr. *mesos*, middle), arises. This consists of two layers,—the *splanchnic*, (Gr. *splanknon* gut) or *visceral* layer and the *somatic* (Gr. *soma* body) or *body-wall* layer: the cavity between them is the cœlom. In the earth-worm embryo these cœlomic cavities first appear as a pair of sacs in each segment. These sacs and their walls continue to grow till finally they meet above and below the alimentary canal, and so form a ring-shaped space around the viscera. It is therefore obvious that, no matter how thin the septa may be, they are fundamentally made of a double layer of the cœlomic wall.

A cœlomic cavity is a characteristic of all higher animals, which are on this account called the *Cœlomata*, no matter how much the cœlom may be reduced or difficult to recognise.

The cœlom is thus not a mere slit or space between the various organs but a sac with its own proper wall of epithelial cells. From these cells always arise the mother-cells of the gametes or reproductive cells. Into the cavity open the nephridial tubes.

Examine the cœlomic fluid from a freshly chloroformed worm, making a smear, which should be rapidly dried in the air, fixed with alcohol, stained with eosin and methylene blue or logwood. The corpuscles will show blue nuclei surrounded by red cytoplasm.

Examine a specimen of the fresh fluid under a cover-glass, using your highest power. Observe the amœboid

movement of the corpuscles, many of which contain vacuoles. Many of the cells soon run together and then break up.

ALIMENTARY CANAL.

We have already seen the large mouth placed anteriorly. In those worms which have an overhanging prostomium, the mouth will, of course, be placed more or less ventrally. The cuticle of the external surface is continuous with that lining the alimentary canal, as can be seen on peeling it off from the anterior and posterior segments. The mouth opens into the thin-walled *buccal cavity* (*Lat.*, *buccæ* the cheeks), which in *Perichæta* is much more protrusible than in most earthworms.

The buccal cavity ends in the third segment in a *pharynx* with strong muscular walls, from the outer surface of which powerful muscles radiate to the body-wall. In the dorsal portion of the groove which marks the junction of the buccal and pharyngeal regions, lies the brain or supra-pharyngeal ganglia. In the fifth segment a small pair of glands opens into the œsophagus. When examined with a lens they are seen to resemble a minute bunch of grapes.

From the pharynx the canal is continued as a comparatively narrow *œsophagus* to about the 14th segment, where the intestine may be regarded as commencing.

In the 8th and 9th segments the œsophagus is greatly strengthened by an increase of the muscular, particularly the circular, layer. This portion, known as the gizzard, has a chitinous lining and can readily be recognised as a firm pea-like body when pressed with the finger. Attention has

already been drawn to the fact that the septum on each side of the gizzard, that between the 8th and 9th segments, is absent or incomplete. You may also observe that the gizzard sometimes encroaches on the tenth somite, pushing the septum backward.

The soft portion of the œsophagus as well as the intestine is beaded where the septa pinch it. You will note that in many animals the gut is very much longer than the body and is coiled and twisted so as to pack into the body-cavity. By this great length a large amount of surface is able to act on and absorb the food. In other animals the absorbing surface is increased by the presence of folds or spiral valves, such as you see in the short-gutted dog-fish.

In the earthworms where the alimentary canal is quite straight and no longer than the body, an extra amount of surface is obtained by the septa nipping it so as to form a series of pouches like a string of closely pressed beads. In most earthworms there is a deep fold or gutter, called the *typhlosole* (Gr. *typhlos* blind, *solen* channel), on the dorsal surface of the gut, which forms a longitudinal ridge internally and so increases the absorbing surface. It is commonly stated that the *typhlosole* is absent or rudimentary in *Perichœtœ*, but in this species at least, it is clearly present as a prominent longitudinal ridge in the latter half of the intestine, becoming less distinct more anteriorly.

In the 26th or 27th segment will be seen a pair of small pouches, the *cœca* (Latin, blind) which arise from each side of the gut and project forward for a distance of three segments. They are usually found empty.

These *cœca* are highly characteristic of *Perichœta*, being

found in almost all species, while they are absent from all other Indian and European genera.

The intestine terminates at the anus on the posterior surface of the last segment.

VASCULAR SYSTEM.

The blood is a red fluid, owing its colour to hæmoglobin dissolved in the plasma and not associated with special red cells as we find in the blood of vertebrates. The white amœboid corpuscles are small, irregular and nucleated.

The blood is best examined by removing from a freshly chloroformed worm a large piece of vessel, such as one of the "hearts," pinching it between two pairs of forceps. Some should be examined fresh under a cover-glass. A smear should also be made and stained in the same manner as the cœlomic fluid.

In a recently killed worm the vessels are readily recognised by their red colour due to the contained blood. If the worm has been long preserved in spirit the vessels become yellowish white and less conspicuous, though firmer and more easily dissected. It is best to dissect a worm that has been killed from three to six hours as the blood has then clotted without losing its colour.

The blood is contained in a system of closed vessels not communicating, as in the *Arthropods*, with the perivisceral spaces.

The principal vessels are three *longitudinal:* (*a*) the *dorsal*, which can be recognised externally as a dark streak, showing through the body-wall; (*b*) *ventral* or *sub-intestinal*,

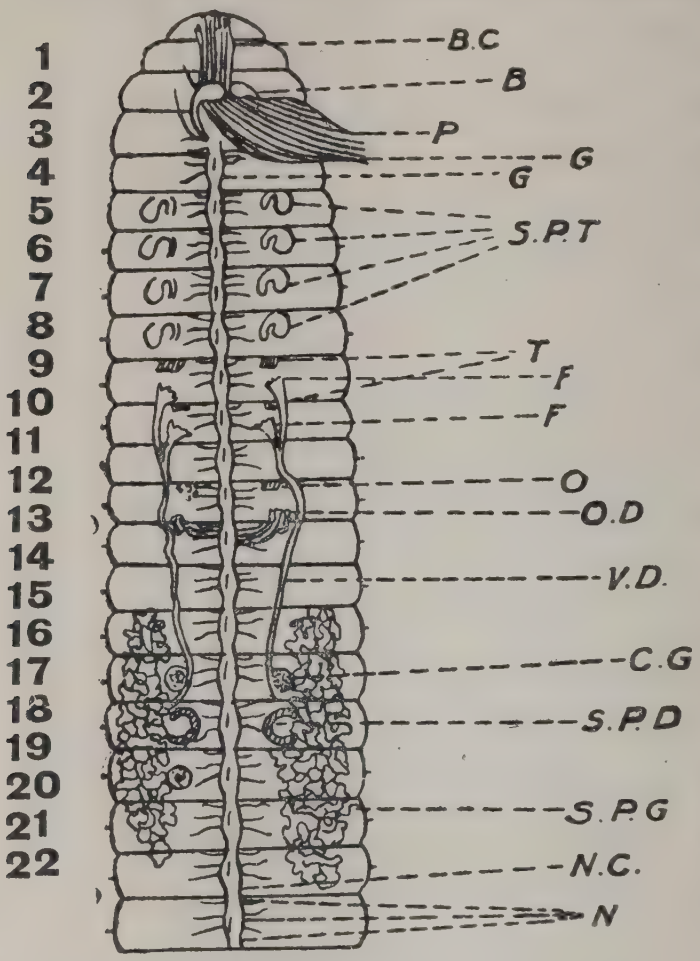
below the intestine, dorsal to the nerve cord ; (*c*) the *subnervian*, placed close to the nerve cord on its ventral side. The dorsal and subnervian are united in each of the middle and posterior segments by (*d*) *commissural vessels*, one on each side, making a complete vascular ring in the body-wall.

In front of the twentieth segment the dorsal vessel becomes enlarged and its wall more muscular. In the 10th to the 13th segments it is united with the sub-intestinal vessel by four pairs of large and contractile vessels, generally known as the (*e*) *hearts*.

In smaller and moderately translucent worms the blood can be seen with a lens or the low power of the microscope to be driven forwards by rhythmical contractions of the dorsal vessel and in the hearts to be driven from above downwards. The blood is prevented from flowing in the opposite direction by numerous valves, which can be seen to cause a beading of the vessel if an attempt be made to squeeze the blood backwards. The walls of the ventral and other vessels are not contractile. The vessels break up in the various organs as well as in the intestinal and body walls, into minute capillaries, extending even between the cells of the epidermis, which is the respiratory organ of the earthworm, where the blood is exposed to the oxygen of the atmosphere. From the dorsal vessel in each segment a short branch will be seen running to terminate dorsally in a small white fluffy ball of peritoneal cells probably of the nature of *blood-glands*.

The vessels differ considerably even in closely allied species. The subnervian may be absent. There is often a pair of lateral neural

vessels, a supra-intestinal and an infra-intestinal longitudinal vessel, parallel with the dorsal and ventral vessels above described, but in closer contact with the alimentary canal. The number of hearts varies. The dorsal vessel may be double in the anterior region as in the giant *Megascolex cæruleus*. The manner in which the longitudinal vessels anastomose and terminate in the anterior segments varies greatly.



REPRODUCTIVE ORGANS.

To dissect these the worm should be pinned out under spirit in preference to water.

All earthworms are hermaphrodite, and multiply only by sexual processes, though their power of repair when mutilated is very great.

Fig. 14.—*P. postuma. Intestine and Œsophagus removed*—B. C. Buccal cavity. G. Ganglion. F. Funnel. O. Ovary. O. D. Oviduct. N. C. Ventral nerve cord. N. Nerves. Other letters as in Fig. 13.

The essential organs are the *gonads* and their ducts. The gonads are arranged metamerically, one pair of *testes* in segment X, another pair in the following segment XI.

In the adult worm there is only one pair of *ovaries*, those in the thirteenth segment ; but in the embryo of such forms as have been studied, there is another pair in the 12th which soon disappears, and is only recognisable in abnormal adults. All four pairs of gonads arise (as in all *Cœlomata*) as thickenings on the wall of the cœlom. At first it is impossible to tell by their structure which will be testis, which ovary. The anterior pair of ovaries only makes its appearance to quickly disappear. The testes in the young adult worm usually shed the sperm-mother-cells into the *sperm-sacs*, where further development takes place, the testes meanwhile shrinking so that to see them properly a young worm should be selected for dissection.

The sperm-sacs or *vesiculæ seminales* (Latin seminal bladders) are seen in segments X and XI as two pairs of large irregular lobulated sacs which when fully developed extend up on each side of the œsophagus and meet dorsally above it.

These should be carefully dissected from the œsophagus, the intestine cut across about the 24th segment and carefully dissected from the body-wall by repeated snips of the scissors or touches of a very sharp knife. The ventral blood vessel and nerve cord should be left uninjured. Special care must be taken in the region of the sperm-sacs, as the œsophagus is very likely to break off from its connexion with the gizzard if roughly handled. When the whole anterior part of the alimentary canal, as far as the third segment has been dissected up and turned aside, examine the structures exposed.

In the thirteenth segment attached to the anterior septum close to the ventral mid line will be seen a pair of small granular patches, the *ovaries*, one on each side of the nerve cord. They are small flattened pear-shaped organs, the base attached to the septum, the apex pointing backwards. One should be removed, fixed in Muller's fluid, stained with logwood and eosine and longitudinal sections made; or it may be simply stained with eosine and examined at once.

Ova in all stages may be seen—at the apex ripe ova, large round cells enclosed in a *vitelline membrane*, the protoplasm containing a granular *yolk* (Lat. *vitellus*) with a large round nucleus and nucleolus, known as the *germinal vesicle* and *germinal spot* respectively.

At the attached base of the ovary is seen a mass of small undifferentiated cells, the *germinal epithelium*, while between the base and the apex ova are seen in all stages of development.

The *oviducts* can be seen as a pair of funnels or short trumpet-shaped tubes, piercing the septum between the 13th and 14th segments. The mouth of each funnel is ciliated and in the same line as the ovary of its side. On piercing the septum the ducts run inwards and slightly backwards to meet in the ventral mid line below the nerve cord and pass through the body-wall, to open by a common aperture at the anterior margin of the girdle on the 14th segment.

The *spermathecæ* (Gr. *theke*, a receptacle) in which after copulation the sperm of the other worm is stored, are four pairs of pearly translucent sacs in segments VI, VII, VIII and IX. The thick muscular septa in this region should be

cleared away to expose them. Each sac gives off from its median aspect a narrow process or diverticulum, about the same length as the sac itself. This is usually of a dead white colour and may have no lumen. Each sac opens by a separate small pore on the ventral surface of its own segment.

MALE REPRODUCTIVE ORGANS.

The dorsal and lateral walls of the sperm-sacs should be carefully removed from one side to see the *testes*. These are only recognisable in young worms, becoming atrophied in the adult. They are two pairs of minute white bodies attached to the surface of the septa in front of segments X and XI, close to the middle line.

The sperm-ducts or *vasa deferentia* arise as ciliated funnels on the anterior surface of the septa behind segments X and XI, there being a funnel for each testis. Each funnel is chalk-white in colour and its margins folded like those of a paper filter, the name "rosette" being sometimes given it.

The ducts of the ovaries, we have seen, open at once on the next segment. Those of the testes are long and traverse several segments before opening by the well-marked pores seen on the 18th segment.

The ducts of the first pair of testes meet those of the second in the 12th segment where they become enclosed in a common sheath. They then run a somewhat contorted course on the body wall close to the nerve cord till they reach the 17th segment, where they curve outwards behind the copulatory glands to enter the spermiducal duct just as it leaves the gland.

The *spermiducal glands*, sometimes called *prostates*, are a pair of large white lobulate racemose glands, lying one on each side of the intestine from about the 16th to the 20th segment, more or less. Each consists of (1) a loosely lobulated glandular portion covered by peritoneum and lined with secretory epithelium, and (2) a muscular duct which is joined by the *vas deferens* of its own side and then curves inward in a sickle-shaped course to open as the male pore on the papilla already seen on the 18th segment.

The name "prostate" is objectionable as suggesting a false homology with the organ of that name found in Mammals. The term "spermiducal glands" is also unsatisfactory, as in a whole family of worms, the *Acanthodrilidæ*, they have no connection with the sperm-ducts but open independently on separate somites.

None of the European family, *Lumbricidæ*, possess these glands. They may be very small in some *Perichætidæ*, occupying only one segment, or so large in *Hoplachætella* and a species of *Perionyx* as to reach from the 10th to the 40th segment. Their function is unknown.

In segments XVII and XIX, in situations corresponding to the suckers, two pairs of white copulatory glands may be seen projecting into the cœlom.

Copulation is effected between two animals by applying their anterior ventral surfaces together, in which position they are held by the sticky secretion of the girdle, and in some species, especially that more particularly described in this chapter, by suckers in the region of the genital pores. The sperms during connexion are passed out of the sperm-duct of the one worm into special sacs or *spermathecæ* (Gr.

theke, receptacle), placed further forward on the other, and there stored up. After the worms have separated, the girdle secretes a tough tube of chitin, which forms a tolerably wide belt round the body. The worm gradually wriggles backwards out of this belt, and as it passes over the mouths of the oviducts and spermathecæ, eggs and sperms, as well as a quantity of nutrient albumen from certain glands in the skin, are squeezed out into the cavity of the belt. When the belt has finally been slipped off the worm, its ends dry and contract to form a closed cocoon or capsule containing the gametes and albuminous fluid.

The sperms then fertilise the ova, of which there are at first several in each cocoon, but as a rule only one egg matures. On the other hand a single egg not infrequently gives rise to twins. The embryo in the cocoon feeds on the milk-like albuminous fluid, and when hatched resembles the parent worm.

NERVOUS SYSTEM.

The nervous system can be exposed by the same dissection as that described above for the testes and ovaries. The posterior portion of the intestine should also be lifted up when the whole ventral chain can be seen as a white cord close to the body-wall in the ventral mid line.

In the embryo the nervous system consists of a double chain of ganglia, a pair for each segment, united by a double cord. The first trace we find of it is two longitudinal thickenings of the epiblast on the ventral aspect. The thickenings gradually lose their connection with the ectoderm, and come to lie first in the thickness of the body-wall and ultimately for the most part quite in the body-cavity. In the most prim-

itive Oligochæte we find the nerve system retains its connection with the epidermis throughout life.

This is *Æolosoma*, a pretty little transparent worm, marked with bright green, orange or other coloured dots, very common in fresh water tanks in Bombay.

The first pair of ganglia are dorsal in position and known as the *brain* or *supra-pharyngeal ganglia*. In the adult they have shifted back to the third somite where they can readily be found on the dorsal side of the groove that marks the junction of the buccal and pharyngeal portions of the alimentary canal. They form a two-lobed mass, each lobe being the shape of a comma, with the stalks continued as the *circumpharyngeal connectives* downwards and backwards in the bucco-pharyngeal groove to unite below with the *first ventral ganglia*.

The brain gives off nerves to supply the integument around the mouth. The circumpharyngeal collar supplies the anterior two somites and also *visceral nerves* to the pharynx. The first ventral or *subpharyngeal ganglia* are in the fourth somite, and not only supply it, but send branches to the anterior somites also. Behind this in most worms the longitudinal connectives are enclosed in a common sheath and placed so close together as to look like a single cord with a ganglionic enlargement in each somite. In this species the ventral connectives can be seen in some specimens as a distinctly double cord in several of the anterior somites.

In each somite can be seen three pairs of nerves,—two given off by the ganglia and one anteriorly from the cord to ramify on the septum.

The nervous system of the Earthworm, as well as of all Annelids, is peculiar, in that the connectives contain nervé cells, as well as nerve fibres, whereas in higher animals the nerve cells are restricted to the ganglia. Three clear-looking "*giant-fibres*" are noticeable in the upper portion of the ventral cord.

SPECIAL SENSE ORGANS.

We can recognise no eyes or organs of vision in the Earthworm, but it is certainly conscious of the difference between light and darkness. If a flash of electric light be brought to bear on a worm during his nightly excursions, he will quickly withdraw to his burrow. Worms appear absolutely insensitive to sound, but here we must distinguish between the sense of hearing and the feeling of vibration. A window pane cannot hear, yet the sonorous vibration from a gun will shatter it. The shrillest whistle does not seem to disturb an Earthworm in the least. That there is a sense of touch or feeling is obvious; the trodden worm will turn; tapping or hammering the ground in its neighbourhood causes the worm to retreat deeper in its burrow.

The worm has probably a sense of smell. It is very fond of onions, and if one be placed near it at feeding hours the worm is sure to find the onion. There must be a sense of taste also. If a number of odourless leaves of various kinds be placed in the neighbourhood of the worm, probably one kind will be quite consumed before the others are even touched.

THE NEPHRIDIA.

The *nephridia* (Gr. *nephros*, kidney), of whatever appearance they may be, are essentially tubular organs lined

with an epithelium which excretes the nitrogenous waste. They are derived from the cœlom and communicate with its general cavity by one end, with the exterior of the body by the other. The cœlomic opening in the Earthworm is a ciliated funnel known as the *nephrostome*, the external opening as the *nephropore*.

There is a considerable variation in the structure of the nephridia among the Earthworms. In *Perichætæ* the tubules form a diffuse network on the body-wall and the ciliated funnels are numerous in each segment ; the nephropores, also numerous, open all round the circumference. The pores are very small and can only be seen in sections. In *Perichæta* the nephridia, owing to the diffuse nature of their structure, are only visible to the naked eye as a roughness or fluffiness of the body-wall.

This type of nephridium is known as the *diffuse*, as distinguished from the large, or *paired nephridia*, found in most families of Earthworms.

Another type of nephridium is the *compound nephridium*, where a large number of tubules, each commencing with a ciliated nephrostome, unite to form a fluffy mass, resembling a mop. They are found in the pharyngeal segments and open into the alimentary canal.

Although the nephridia of *Perichæta* in the adult are always of the diffuse type, in the embryo we find the primitive nephridia are paired in each segment.

The paired nephridia are so called as there is usually one pair in each segment. They are large and visible to the naked eye. Each nephridium opens by a funnel into the cœlom, and is an unbranched tube, usually thrown into three loops, varying in width and in the

character of the epithelial lining. The external pores of the paired nephridia are in definite sites.

Large looped nephridia can be seen in the Indian *Perionyx*, and in all the European family *Lumbricidæ*. *Megascolex* has both large and diffuse nephridia. Some genera have two and even three pairs of nephridia per segment.

THE BODY-WALL AND GENERAL STRUCTURE AS SEEN IN TRANSVERSE SECTIONS.

The body-wall from without inwards is composed of—

(*a*) The *cuticle*.
(*b*) The *epidermis*.
(*c*) The *circular layer of muscle*.
(*d*) The *longitudinal layer of muscles*.
(*e*) The *peritoneal* lining.

The cuticle is not a layer of cells, but a secretion of the underlying epidermis. It readily peels as a thin film off worms that have been preserved some time. Under the microscope it is seen as a transparent colourless membrane, marked by fine lines or striæ and showing circles of openings through which the setæ pass. Frequently some of the setæ remain attached to the cuticle, and it is then seen that only

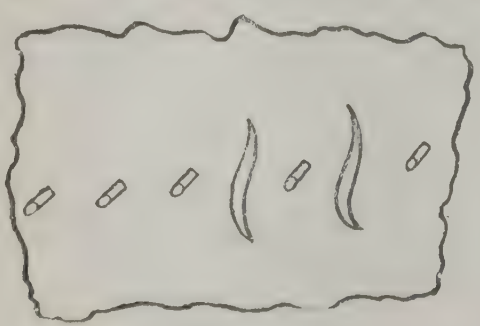


Fig. 15.

Cuticle of Perichæta with two setæ and five empty sleeves.

about a third of the length of the seta projects above the surface. At the setal openings the cuticle may be seen turned in like small sleeves to surround the setæ when in position. Numerous minute openings for the nephridia may be seen scattered without any apparent arrangement. The setæ may be picked out with a fine pair of forceps or a por-

tion of integument may be boiled in *liquor potassæ* to isolate them. They should be examined in water. They are seen to resemble an italic letter *f* in shape, the cross-bar being a very slight projection. Like the cuticle, they are non-cellular, a secretion of the epiderm composed of *chitin*.

The ectoderm consists of a single layer of epithelial cells, most of which stain feebly and have very small nuclei.

Between these feebly staining cells are seen glandular cells of a pear-shape, stalk-end outwards, containing deeply stained granules. These cells secrete the mucus which keeps the surface slippery.

Next is the circular layer of muscle. The muscles of the *Annelids* are peculiar and resemble those of the *Nema-*

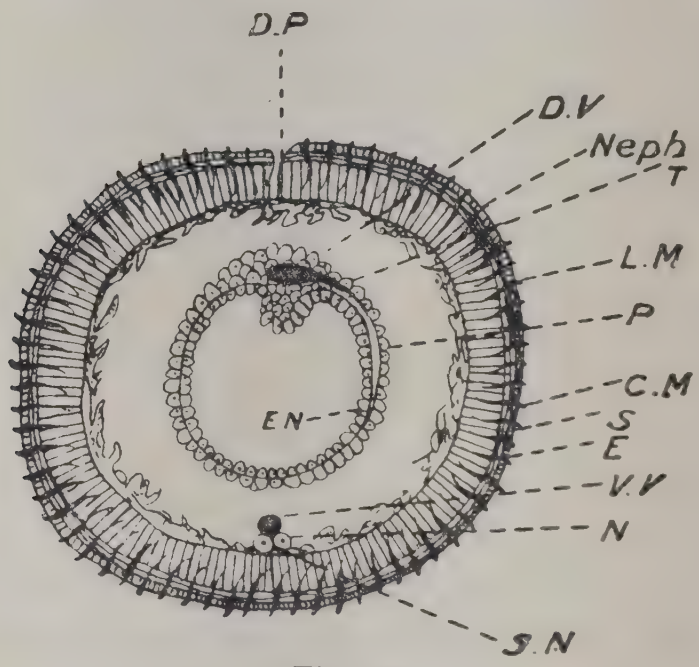


Fig. 16.

Fig. 16.—*Perichæta. Transverse section posterior region—*

D. P.	Dorsal pore.	S. N.	Subnervian vessel.
D. V.	Dorsal vessel.	V. V.	Ventral vessel.
Neph.	Nephridia.	P.	Peritoneum.
N.	Nerve cord.	T.	Typhlosole.

tode worms, in that each cell has a central unmodified portion of protoplasm enclosing the nucleus and surrounded by the striated contractile protoplasm.

The longitudinal layer is thicker than the circular.

The peritoneum is seen as a thin membrane internal to the muscles.

All these layers are continuous at the mouth and anus with similar layers of the alimentary canal. Thus the outermost layer of the canal is the peritoneum which, however, in places is many cells thick, forming the "yellow-cell tissue," the cells being, as already described, club-shaped and full of small refractive globules.

The muscular layers of the gut are feebly developed, the longitudinal layer is outer, the circular inner. The lining membrane is a single layer of epithelial cells, separated from the muscular coat by a thin layer of very vascular

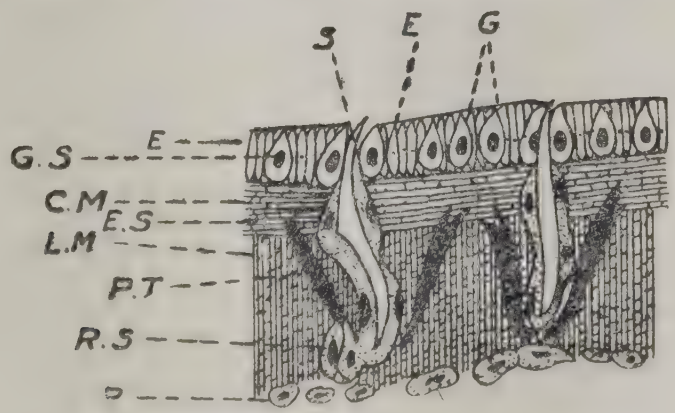


Fig. 17.

Fig. 17.—*Portion of Fig.* 16, *more highly magnified*—

S. Seta.
E. Epithelium.
G. Glandular cell.
E.S. Epithelium of setigerous sac.
R. S. Reserve seta.
C. M. Circular muscle.
L. M. Longitudinal muscle
P. T. Protractor muscle.
P. Peritoneum.

connective tissue, known as the sub-epithelial layer. It is probable that the whole of the epithelium lining the alimentary canal, except that in the buccal cavity and close to the anus, is derived from the hypoblast. (See description of stomodæum and proctodæum, p. 118 and p. 150.)

The ectoderm has been described as a single layer of epithelial cells. The region of the girdle is an exception as in all the true Earthworms there are here two layers of cells, many of which are of a glandular character, to secrete the cocoon case.

The setæ will be seen set in sacs reaching inwards to the peritoneum, lined with a sheath of the epidermis, by the innermost cells of which they are secreted. From the inner end of the sheath can be seen the *protractor muscle* of the seta passing obliquely outwards to join the outer circular layer of muscles. Contraction of these protractors causes the setæ to project well above the surface. Young developing setæ, which will replace the functional ones when worn out, may be seen in their sacs or follicles close to the peritoneum.

RELATIONSHIP OF THE EARTHWORM.

In the English language the word " worm " is used colloquially to indicate any small cylindrical, soft-bodied animal, devoid of conspicuous limbs. Linnæus classified the majority of these in a sub-kingdom which he called *Vermes*, the Latin for " worms."

Further study of their structure and development showed such fundamental differences, that now-a-days most Naturalists divide the Worms into at least three *phyla* (Gr. *phylon*, a tribe) or sub-kingdoms.

Of these the most lowly organised phylum is known as the *Flat worms* or *Platyhelminthes*, (Gr. *platus*, flat, *helminthos*, a worm). Many of them, such as the Tape-worms and Flukes are parasitic in other

animals. They possess no cœlom or body-cavity, their internal organs being embedded in a mass of tissue or parenchyma. Some have no alimentary canal and those that have one are without an anus.

The *Nemathelminthes* (Gr. *nema*, thread) comprise several orders which really have few features in common except that all are unsegmented "vermiform" or thread-like in shape and devoid of any appendages except, in rare cases, bristles. They have no blood-vessels or special respiratory organs ; there is always a body-cavity containing fluid, but whether it is a true cœlom or not is doubtful. Many of them such as the round-worm, thread-worm, whip-worm and guinea-worm, are common parasites of man.

The Earthworms belong to the third phylum, *Annelida* (Latin *annulatus*, ringed) or segmented worms. They are metamerically segmented, the viscera are separated from the body-wall by a cavity which is a true cœlom lined with epithelium. They do not possess jointed limbs like the *Arthropods*, but most of them are armed with setæ embedded in, and secreted by the skin.

The Annelids are divided into classes one of which, the *Chaetopods* (Gr. bristle foot) includes the *Polychætæ* (Gr. *polys*, many) or Marine worms, and the *Oligochæta* (Gr. *oiligos*, few), which includes the Fresh-water worms and Earthworms. The name Oligochæta was given as the Earthworms first studied were European genera, which possess only four pairs of setæ on each somite. As the name has been in use for so long, we may retain it, though the Indian species we have studied often has 140 setæ on some of its segments.

The Polychætes differ from the Earthworm in having their setæ arranged in lateral muscular processes or parapodia, in often possessing gills, and in that the sexes are usually separate.

The Oligochætes may be divided into two sub-orders—the *Limicolæ* (Latin, mud-dwellers) and the *Terricolæ* (Latin, earth-dwellers) or true Earthworms. In the former, which, as their name implies, live in fresh water or mud, the male pore is always in front of the female pore. The eggs are large, there are large egg-sacs and the clitellum is composed of a single layer of cells and never begins further back than the 11th segment.

The true Earthworms have small eggs and small egg-sacs, and except in one family (*Moniligastridæ*) a citellum composed of two layers of cells; the ovary is in the 13th, the female pore in the 14th segment, always in front of the male opening.

The families of Earthworms found in India are—

(1) *Moniligastridæ* (Latin *monile*, a necklace, *gaster*, stomach), so called because they often have several—four, even six—gizzards. They form a connecting link with the mud-worms in having an inconspicuous clitellum only one cell thick, placed far in front, on segments X—XIII and the male pores on segments X—XII. Only four pairs of setæ in each segment.

(2) *Perichætidæ*, (Gr. *peri*, around) of which we have studied one species. Setæ numerous in each segment. Male pore on XVIII segment. Spermiducal gland generally racemose or lobate. Indian genera, *Perichæta*, *Perionyx*, *Megascolex*.

(3) *Acanthodrilidæ* (Gr. *akanthos*, thorn). Setæ either 8, 12 or ∞ The spermiducal glands tubular, opening separately from the sperm duct on segments XVII and XIX. Male pore on XVIII. These worms are probably not indigenous to India, but one genus, *Benhamia*, is often found here, perhaps imported from Africa.

(4) *Lumbricidæ*. These are the common worms of Europe. Specimens may occasionally be found in botanic gardens in India. Setæ four pairs on each somite. Male pore on segment XV generally, perhaps in front of it. Clitellum far back, segments XXVII—XXXVIII, usually about XXX—XXXVI. No spermiducal glands. Gizzard far back.

To face page 97.

Fig. 18.—Panulirus, Dorsal View of Female.

Fig. 19.—Panulirus, Ventral View of Female.

PANULIRUS OR "THE SPINY LOBSTER" OF BOMBAY.

This animal is to be found in abundance all the year round on the coasts of Bombay.

Though locally called Lobsters, they do not belong to the same genera or even to the same family as the English Homarus or Norwegian Nephrops, and the inexperienced student attempting to study the anatomy of the Cray-fish or Lobster, will soon become woefully muddled when he attempts to reconcile the accounts of the Lobster in English text books with his personal observation of Panulirus.

You may hold Panulirus in your hand with impunity as he possesses none of the powerful forceps with which his European cousin, the Lobster, or some of the Indian Prawns can pinch and wound the unwary investigator.

If alive he will probably make a croaking noise as you lift him. This sound as you can verify yourself, is caused by rubbing the first movable joint of the large feelers against the neighbouring fixed part.

He may perhaps startle you by forcibly flapping his tail against the under surface of his thorax. When in his native haunt, the sea, he is able to suddenly dart backwards by similar powerful strokes of the tail, but the usual mode of progression is swimming by gentle strokes of the flat tail-fin, while the swimming feet all row together with an even swing like the oars of a boat. When on the bottom of the sea he walks on the long thoracic legs.

Note the movement of the jaw apparatus. Each jaw moves horizontally to and from the middle line of the body—not up and down as do the jaws of a dog or man.

Next look under the anterior edge of the large shield-like covering of the cephalo-thorax. You will notice a small scoop or paddle-shaped appendage, moving rapidly to and fro two or three times a second. This is the paddle or *scaphognathite* (Gr. *scaphe*, boat, *gnathos*, jaw), by means of which the water entering the gill-chamber from behind is baled out in front, so that a continuous current keeps bathing the gills to enable them to absorb the oxygen dissolved in the water and get rid of the carbonic acid.

The course of the current is easily demonstrated by returning the animal to the water after it has been in the air for some time. On re-immersion, bubbles of air are for some time seen to come out from under the anterior edge of the gill-cover. Should this not satisfy you, if you put some finely powdered carmine or indigo in the water just behind the gills, you will soon see the coloured current pouring out in front of the scaphognathite.

The whole body of Panulirus is covered by an integument composed of a number of epithelial cells which corresponds to the epidermis of man and higher animals. These cells secrete a substance which forms a continuous layer all over the surface of the body and limbs, and at the mouth and anus is continuous with the lining of the gullet, stomach and most of the intestine. This layer is known as the *cuticle* and throughout contains a substance known as *chitin* (Gr. *chiton*, a coat). Here and there it is impregnated with salts of lime to form the rigid armour-like portions of the exo-

skeleton. Any hardened portion is known as a *sclerite* (Gr. *skleros*, hard). By pouring a little strong acid on the hardened skeleton the lime will be dissolved with the ebullition of gas bubbles. You must clearly understand that the cuticle of the invertibrates is not homologous with your own cuticle, or that of other vertebrates, which is composed of a number of flattened epithelial cells, while that of the invertebrates is non-cellular, *i.e.*, only a secretion, and showing no nuclei or cellular structure.

Between each somite of the cephalo-thorax behind the mouth, there is an infolding of the cuticle, each such infolding being called an *apodeme* (Gr. *apodaio*, I partition) to form an internal skeleton, or *endophragmal* system, on the floor of the cavity. These sclerites form in the middle line a tunnel or series of archways over the sternal sinus, the nerve cord and sternal artery. Laterally they resemble the bulkheads of a ship and give attachment to the muscles.

The whole of this cuticular skeleton, including the apodemes and the lining of the fore and hind gut, is moulted periodically.

The body is divided into two easily recognised regions (*a*) A posterior *abdomen* made up of six *somites* (Gr. *soma*, body), freely movable on one another in the vertical plane but having no lateral movement. These somites are all clearly homologous with one another and, except the first, each bears a pair of lateral appendages. Behind all is a seventh segment, the "tail" or *telson*, which bears no appendages and is not a true somite. (*b*) Anteriorly is the *cephalothorax* (Gr. *kephale*, the head), covered dorsally and on the sides by a large rigid shield, the *carapace*, in which there is

little indication of segmentation. Ventrally, however, the presence of a number of transverse bars and of thirteen pairs of appendages will lead you to conclude that the head is composed of five, and the thorax of eight somites.

The structure of a somite may best be studied by taking as a type one from the abdomen, say the third, of which Fig. 20 represents a transverse section, nearly semi-circular

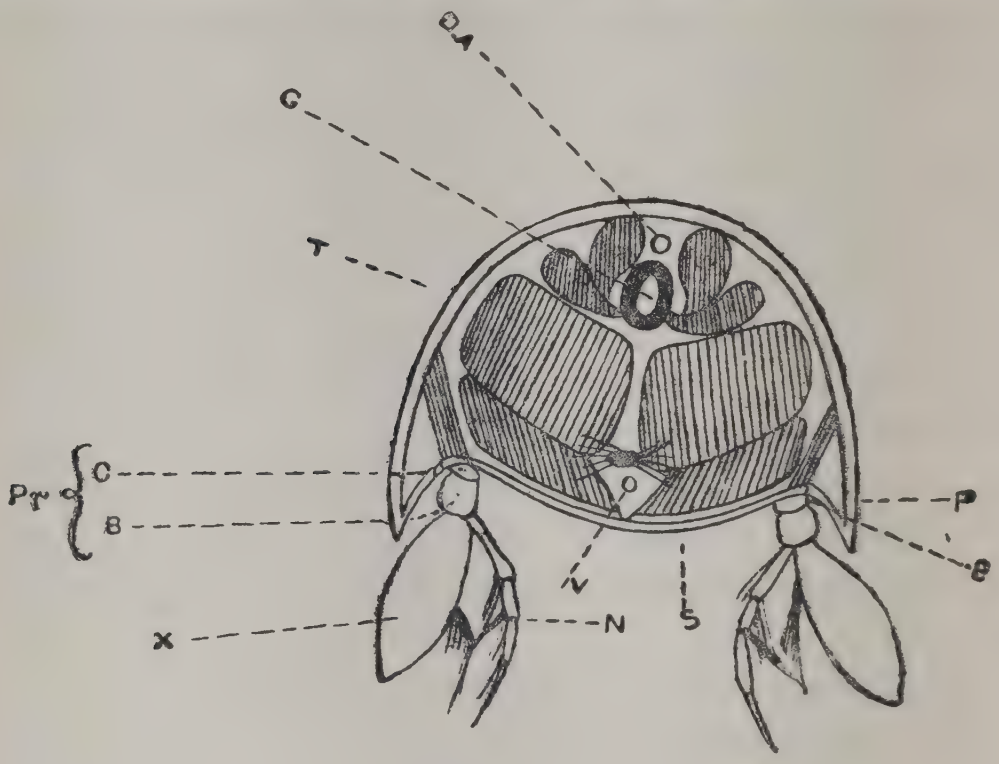


Fig. 20.

TRANSVERSE SECTION OF 3RD ABDOMINAL SOMITE.

C = Coxopodite } *Pr.* = Protopodite
B = Basipodite }
DA = Dorsal Artery.
E = Epimeron.
G = Hind-gut.
P = Pleuron.
N = Endopodite.
S = Sternum.
T = Tergum.
V = Sternal artery.
The black dot above it is the nerve ganglion.
The clear space around is the ventral sinus.
X = Exopodite.
The shaded portions are muscles.

in outline. The exoskeleton of the segment surrounds it as a ring, being hardened by calcification where rigidity or protection is required, and remaining soft where flexibility is necessary. Dorsally the hard exoskeleton forms a broad arch known as the *tergum* (Latin, the back); the lateral portions projecting downwards, and terminating in recurved spine are called the *pleura* (Gr. *pleuron*, side, rib). Ventrally the ring is completed by a narrow straighter bar to the outer ends of which the appendages are articulated. That portion of the bar between the swimming feet is called the *sternum* (Latin, breast-bone). The very small portion of the bar external to the limb and internal to the pleuron is the *epimeron* (Gr. *epi*, upon or above; *meron*, the thigh).

Between these rings of sclerites the integument is soft and flexible to allow of free movement.

The terga of the successive somites overlap one another from before backwards like the tiles of a roof; their movement is restricted to the vertical plane by very neat hinge-joints formed by a short peg on the posterior margin close to the pleuron, which fits into a corresponding socket on the anterior margin of the next tergum.

The appendages are attached by soft arthrodial membranes to the margins of a circular opening in the ventral sclerite, between the epimeron and sternum as already described.

The appendages differ greatly in the sexes. In the female we find a basal stem or *protopodite* (Gr. *protos*, first; podite, from *pous*, *podos*, a leg or foot, signifying a leg segment), consisting of a very short proximal *coxopodite* (*coxa*,

the hip) and a larger distal piece the *basipodite* (*basis*, the base). To the distal end of this are articulated two flat

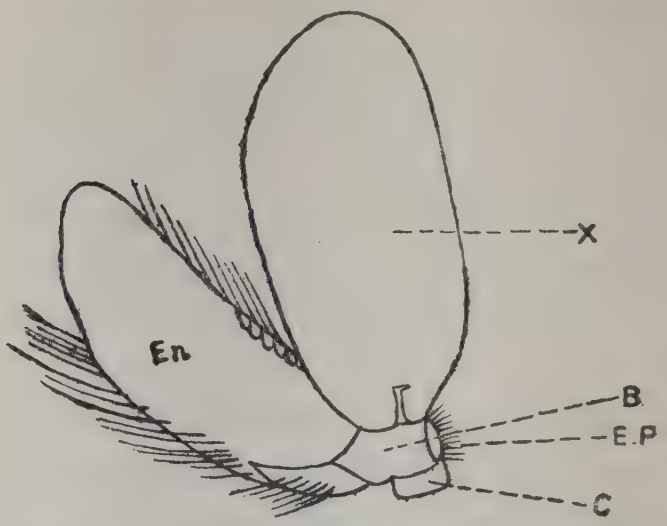


Fig. 21.—Swimming foot of 2nd abdominal somite of female.
B=Basipodite; *C*=Coxopodite; *En*=Endopodite; *X*=Exopodite.

leaf-like structures, an outer *exopodite* (Gr. *exo*, outer) and an inner *endopodite* (Gr. *endo*, inner).

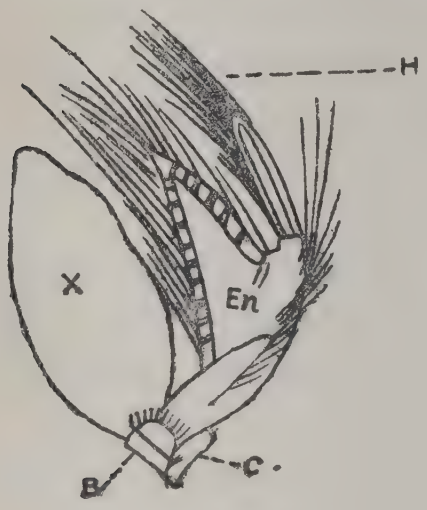


Fig. 22.

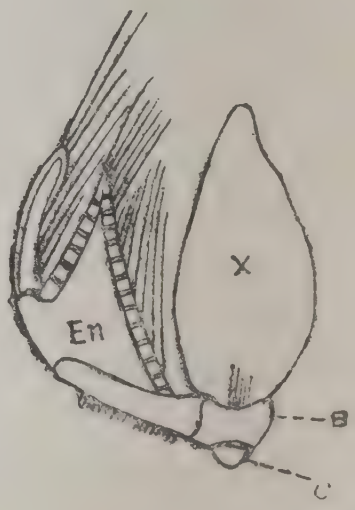


Fig. 23.

Fig. 22.—Swimming foot of 3rd abdominal somite of female.
Fig. 23.— ,, ,, of 4th ,, ,, ,,

The exopodite is shaped somewhat like a rabbit's ear. The greater part is membranous in character, being composed of a double layer of cuticle covering a little connective and muscle tissue ; only the basal portion is calcified.

The inner margin of the endopodite is strengthened by three sclerites. In the appendage of the second abdominal somite the endopodite is a thin membranous leaf, very like the exopodite in appearance but bearing on its margin a fringe of hairs.

The protopodites and exopodites of the next three segments, namely the third, fourth and fifth, resemble those of the second, but become progressively smaller. The leaf of the endopodite is however curiously divided. There is a triangular flap attached along the two proximal pieces ; its free margin strengthened by numerous small white sclerites. The distal piece is a narrow plate with a calcified margin. The margins of the whole endopodite bear numerous long silky hairs to which the eggs become attached when laid.

In the male all the above appendages are smaller and have only one leaf, the exopodite, as the endopodite is quite suppressed.

In the adult of both sexes the first abdominal segment is devoid of appendages. Its tergum has a large buttress on each side just above the hinge, which prevents over-extension by coming in contact with the posterior margin of the carapace.

The lateral appendages of the sixth abdominal somite are very large and with the telson form the powerful five-leaved tail-fin.

The protopodite consists of a single piece. The endopodite and exopodite form two large oval plates, each with a proximal stout, calcified, and a larger distal, membranous portion.

The telson may be regarded as a median appendage of the sixth somite. Ventrally it is for the most part uncalcified, and in its anterior portion is perforated by a longitudinal opening, the anus. Two small oblique linear sclerites are seen on each side of, but somewhat in front of the anus. Dorsally the proximal portion is calcified but the greater part is membranous. The proximal part of this membranous surface as well as of the rest of the " tail-fin " is studded with minute spines.

Cephalo-thorax.

The dorsum and sides of the cephalo-thorax are covered by a large unjointed shield, the carapace, which in front terminates behind the eye-stalks as a broad crescentic notch limited at each end by a stout spine which projects forward above and internal to the eye.

In front of the eyes is a broad plate firmly attached to and looking like an extension of the carapace. This is not its true homology however, and we will later on see that it is part of the united basal joints of the antennæ. The dorsal part of the carapace bears a number of sharp spines which project forward and are most of them arranged in eight longitudinal rows. These sharp spines are some compensation for the absence of the defensive pincers which Lobsters and Prawns possess. They render Panulirus an ugly customer to attack and an uncomfortable mouthful to swallow.

About the middle of the dorsal surface we find a transverse *cervical groove* which runs downwards and forwards on each side of the carapace.

This groove (Latin *cervix*, neck) marks the junction of the head with the thorax and is the only evidence of metamerism in the carapace.

Behind the transverse portion of the groove is a quadrilateral space known as the *cardiac area* because the heart lies below it. The grooves that mark its lateral limits are continuous in front with the cervical and are also continued backward to form two longitudinal grooves, known as the *branchio-cardiac* grooves, because all the portion of the carapace ventral to these grooves forms a cover for the *branchiæ* or gills, and hence is known as the gill-cover or in Greek *branchiostegite*. It represents the united pleuræ of all the thoracic somites.

The sterna of the cephalo-thorax are much more obvious in Panulirus than in the Cray-fish, Lobster or Prawn. Between the five pairs of walking legs is seen a large triangular plate with its apex pointing forward. A number of transverse sutures shows it is formed of the five sterna united together. On separating the foot-jaws their three sterna are seen as a rod continuous with the apex of the triangle, stout tubercles marking the point of union between its segments.

The epimera of the thoracic segments form the inner wall of the gill chamber as a continuous delicate layer which at the dorsal limit of the chamber is continuous with the inner lining of the gill-cover.

The wall formed by the epimera is thin and but slightly calcified except just above the articulation of the appen-

dages. Above the last walking leg it forms a specially strong plate bearing a stout process, in shape and function resembling a shirt stud. The posterior margin of the carapace is tucked or reflected inwards and on each side of this reflection is an oval buttonhole into which the top of the epimeral stud buttons.

Were it not for this buttoning arrangement the posterior portion of the carapace might be tilted upwards and the gills exposed, as the articulating membrane between it and the first abdominal tergum is loose to allow of free flexion and extension.

We have seen that the abdominal appendages are paddle-shaped in accord with their function as swimming organs. The cephalo-thoracic appendages are formed on the same plan but with considerable modification in structure to adapt them for different functions.

Including the antennules they are from before backwards.

Appendages of the head.

I. A pair of antennules } Main function organs
II. A pair of antennæ } of sense or "feelers."
III. A pair of stout mandibles } Jaws.
IV. A pair of first maxillæ
V. A pair of second maxillæ

Appendages of the thorax.

VI. A pair of first maxillipeds } Foot-jaws.
VII. A pair of second maxillipeds
VIII. A pair of third maxillipeds
IX. A pair of first walking legs
X. A pair of second do.
XI. A pair of third do.
XII. A pair of fourth do.
XIII. A pair of fifth do.

In Fig. 26 the appendages are indicated by Roman numerals.

Remove the gill-cover of one side with stout scissors, cutting from behind forward a little external to the branchio-cardiac groove. Keep the scissors close to the gill-cover or you may cut the gills. Make a second vertical cut at right angles to the first, a little behind the cervical groove. Count the gills and note the position in which they are attached. You will find on moving the last walking leg to and fro that none of the gills are disturbed, but on moving any of the other walking legs or the second or third maxilliped, a gill and also a membranous flap is moved to and fro with the limb. These gills as they are attached to the legs are known as *foot-gills* or *podo-branchiæ* (Greek *pous, podos*, a foot ; *branchia*, gills).

Of the other gills you will find four are attached to the epimeron or inner wall of the chamber. As they are opposite the last four walking legs, it is obvious they belong to the last four thoracic segments. They are called the side-gills or *pleurobranchiæ* (Greek *pleuron*, side).

The remaining gills are eleven in number on each side. The most anterior is attached to the membrane which joins the second maxilliped to the thorax. The other ten are attached in pairs to the articular membranes of the last maxilliped and of the first four walking legs. From their attachment they receive the name of " joint-gills " or *arthro-branchiæ* (Greek *arthros*, a joint).

Remove the thoracic limbs one by one beginning with the hindmost. With the point of a knife cut the articular membrane close to the basal piece of the limb so as not to remove the arthrobranch, but be careful to remove the

foot-gill and leaf-like flap. When the articular membrane has been cut all round, a gentle wrench will disengage the two little pegs and sockets by which the limb is hinged.

Number the limbs with a coloured pencil so that you can recognise to which segment each belongs.

The second maxilliped is perhaps the most complete of the limbs and you had better study it first as a type of the biramous appendage.

Like the swimming limbs it is made up of a proximal stem, the protopodite, consisting of coxopodite and basipodite, to the latter of which are attached two terminal divisions, the endopodite and exopodite. Attached to the

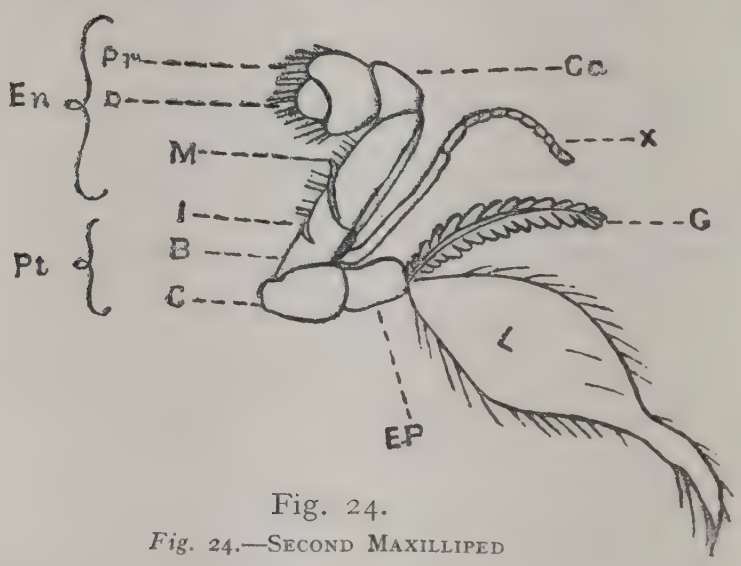


Fig. 24.

Fig. 24.—Second Maxilliped

B = Basipodite
C = Coxopodite.
} *Pt.* Protopodite.
En = Endopodite.
I = Ischiopodite.
M = Meropodite.
Ca = Carpopodite.

Pr = Propodite.
X = Exopodite.
G = Gill.
Ep = Epipodite.
L = Lamella or leaf.
D = Dactylopodite.

outer surface of the coxopodite we find a new structure, a lateral development which runs up into the gill chamber

and bears at its extremity a gill in front and a thin membranous lamella behind.

The whole of this lateral structure, including the calcified podomere articulating with the coxopodite, the gill and the leaf or lamella is called the *epipodite*. The surface of the lamella and especially its margins bear a number of hairs. It is formed of a double layer of chitinous cuticle and prevents the filaments of contiguous gills becoming entangled.

The basipodite is movably articulated with the coxopodite, but distally it is firmly united with the proximal joint of the endopodite so that it may easily be mistaken for a portion of the latter limb-segment which is known as the *ischiopodite* (Greek *ischion*, the hip). A well marked notch at the inner margin indicates the point at which the two segments are fused.

That this is the true homology or explanation of the structure will be at once admitted on comparing the corresponding limb of a Cray-fish or Lobster in which there is a distinct movable articulation between the basipodite and ischiopodite, of which we have only a notch left as a vestige in Panulirus. In the larva the joint is movable.

This ankylosis or immovable union of the basipodite and ischiopodite is characteristic of all the thoracic limbs of Panulirus, whereas in the Lobster we find the joint ankylosed in the great pair of chelæ or pincers, and in the third maxilliped only ; the second maxilliped and all the walking legs have a freely movable joint between the basipodite and ischiopodite. To the latter is movably articulated the *meropodite* (Greek *meron*, a thigh), the longest segment of

this limb. Next comes a short triangular piece, the *carpopodite* (Gr. *karpos*, wrist), next a *propodite* (*pro*, in front), a broad flat segment with a concave distal margin to the centre of which is articulated the terminal *dactylopodite* (Gr. *dactylon*, a finger). All these podomeres of the endopodite are more or less flattened to form horizontal plates, the inner margins of all being covered with stiff bristles or *setæ*.

The exopodite is a long many-jointed, palp-like flattened filament, of which the proximal piece is as long as all the others taken together.

We may regard a typical appendage as made up of a proximal stem or protopodite of two segments, coxopodite and basipodite. The coxopodite bears laterally an epipodite with its gill and lamina. To the distal end of the basipodite an endopodite and exopodite are attached, the latter of a variable number of segments, the endopodite of five, ischiopodite, meropodite, carpopodite, propodite and dactylopodite, enumerating from base to tip.

All the appendages may be regarded as built on the same biramous plan, and all their variations in appearance and function are due to one or more of three factors—

1. Suppression or atrophy of a part or parts.
2. Union or coalescence of parts.
3. Modification of a part or parts.

The third maxilliped much resembles the second, but is considerably larger and stouter. The exopodite is however completely suppressed, though in the Lobster and Prawn it is well developed.

The epipodite has both gill and leaf. The basipodite is firmly ankylosed with the ischiopodite as in all the tho-

racic limbs of Panulirus, the line of union being better marked than in the second maxilliped by a constriction forming a complete ring. The meropodite is in this limb the longest segment. All pieces of the endopodite are somewhat triangular in transverse section, being less flattened than the second maxilliped. The apex of the triangle forms the outer margin of the endopodite, the base being flat and well covered with bristles. The dactylopodite is much longer than that of the second foot-jaw and is covered with hairs.

The maxillipeds and maxillæ are all directed forward in the horizontal plane, so as to overlap one another below the opening of the mouth.

The first maxilliped is much modified. The two segments of the protopodite have become broad thin plates with an inner thin cutting edge fringed with stiff setæ. The epipodite has become a thin membranous plate with no trace of a gill.

The endopodite is a small oval plate, its inner margin setose. The exopodite is relatively very large. Its proximal joint forms more than half its length ; the remaining nine joints are much broader than long, and together form an oval plate fringed with setæ, and twisted at the base through an angle of about 150 degrees, so that the anatomical inner surface looks outward.

The walking limbs are much alike. The first is the shortest and stoutest. The coxopodite, short and irregular in shape, bears at its outer dorsal angle an epipodite, the proximal portion of which is calcified and bears a gill and leaf. The basipodite is firmly ankylosed with the ischiopodite, the two together being about as long again as the coxopodite. The meropodite in this limb is the longest segment, the carpo-

podite is short, the propodite long, bearing a few setæ on the inner surface of its distal extremity. The dactylopodite forms a sharp claw or talon and is almost covered with setæ.

The second leg is longer and more slender, but otherwise resembles the first.

The third is the longest of the legs. There are fewer hairs on the propodite. On the dactylopodite the hairs form two lateral fringes. In the female the ventral

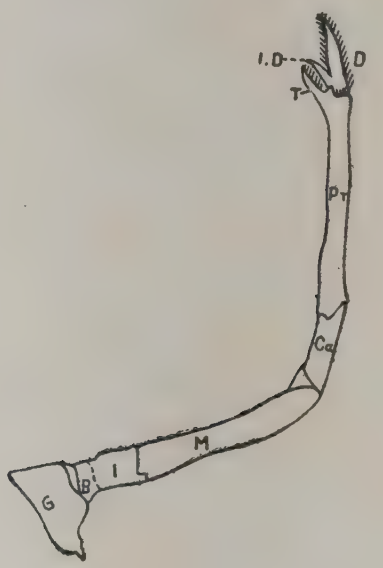


Fig. 25.

LAST WALKING LEG OF FEMALE.
D = Dactylopodite.
ID = Inner opposable process of Dactylopodite.
T = Inner distal process or "Thumb" of Propodite
(Other letters as in Fig. 24)

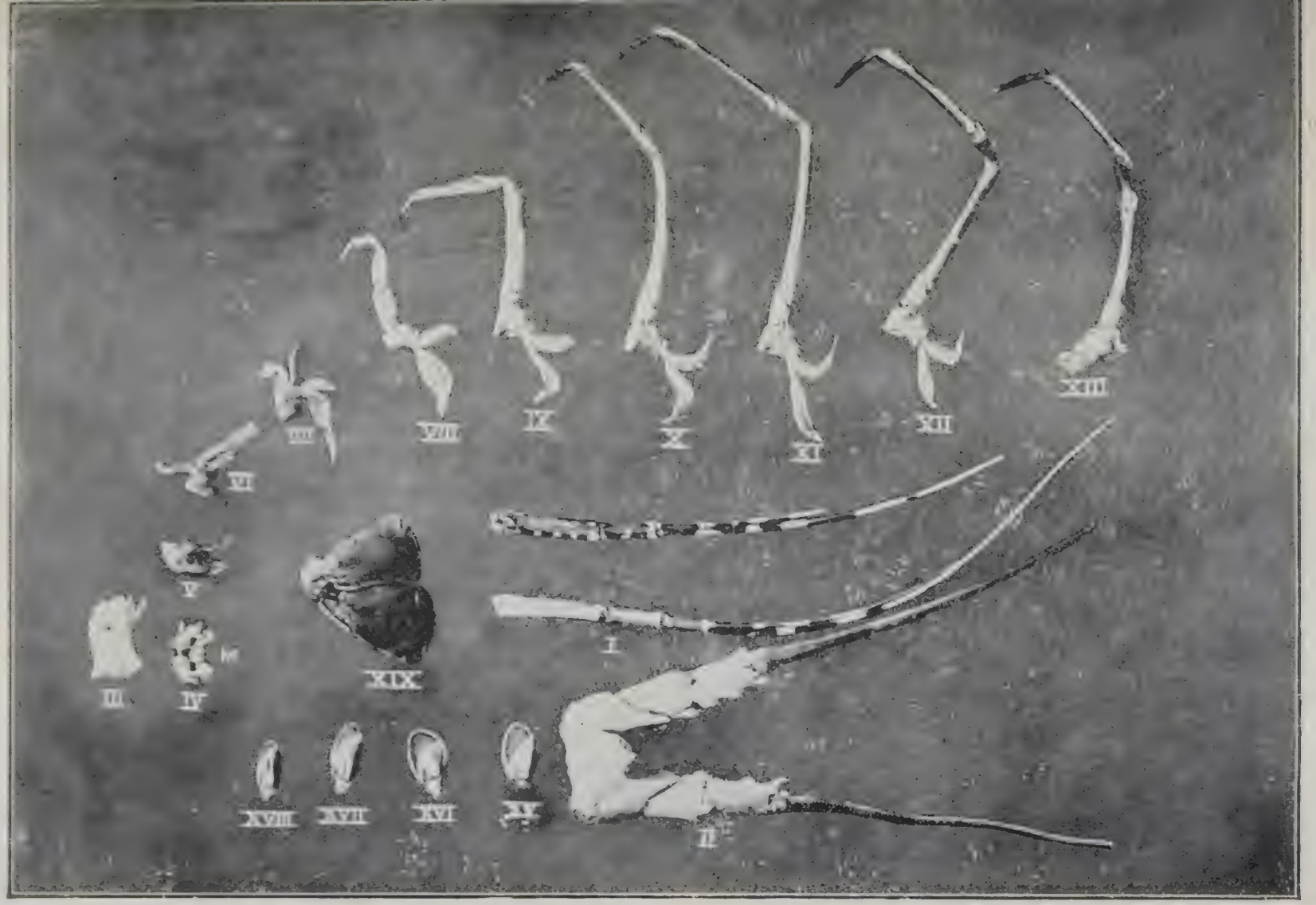


Fig. 26.—Appendages of Male.
M. Metastoma, which has not been separated from IV, the 1st pair of maxillæ.

surface of the coxopodite close to the sternal articulation shows a small pin-hole which is the orifice of the oviduct.

The fourth resembles the third.

The fifth differs from the other legs in having no epipodite and consequently no gill. In the male the ventral surface of the coxopodite has a large opening for the vas deferens. The propodite is about the same length as the meropodite. The dactylopodite is claw-like.

In the female, the propodite is the longest segment and the inner angle of its distal end is prolonged to form a spine against which the dactylopodite can be opposed so as to form a small pincer or forceps. The dactylopodite is somewhat bifid having a large outer claw and a short inner one which forms the outer blade of the forceps. See Fig. 25.

This is the only representative in Panulirus of the powerful forceps so characteristic of Cray-fish, Lobsters, Prawns and Crabs, and it is worthy of note that while all these Crustaceans have the anterior walking legs chelate, it is only the posterior limb of the female Panulirus that is chelate, while the male has no trace of forceps.

The Appendages of the Head.

To the parts of antennæ special names are given, the termination "*podite*," *i.e.*, a "leg piece," being changed to "*cerite*" (Gr. *keras*, a horn or feeler).

In the case of the jaws the termination "*gnathite*," Greek for "jaw piece," is often used, *e.g.*, protognathite, scaphognathite, etc. (Gr. *gnathos*, jaw).

The second maxilla is so overlapped by the first maxiliped as to be almost concealed from view. It presents the appearance of two thin plates, the inner of which is soft and membranous, its inner margin fringed with hairs and divided into three serrations. The proximal of these represents the coxopodite, the second, the basipodite, and the third possibly the endopodite. The outer chitinous flap which lies under the cervical groove is the rapidly moving paddle by means of which water is continually baled out of the gill-chamber. It is the epipodite probably united with the exopodite. It has received the name scaphognathite from its boat-shaped outline. The function of this limb being mainly to assist in respiration, its masticatory portion is uncalcified, feeble and degenerate.

The first maxillæ are more obvious than the second in the living animal, being more exposed and nearer the middle line. Each resembles the Prince of Wales' crest in shape and is firm and well calcified. The middle segment, the largest, is the basipodite, the inner, the coxopodite, both having a cutting edge set with stiff setæ. The outer piece is the endopodite, an oval plate fringed with short soft hairs.

In front of the maxillæ and looking like another softer pair of jaw appendages is the *metastoma* (Gr. *meta*, behind, *stoma*, the mouth) (Fig. 26 M), which forms a soft lip and consists of one median and two lateral lobes, the former being strengthened by two pairs of small sclerites.

Before removing the mandibles open and close them repeatedly to observe the points about which they move

Note on the cleaned skeleton that the lateral bulge of the carapace in front of the cervical groove is almost filled by the outer portion of the huge mandible. In front of the mouth you will see a small soft flexible upper lip or *labrum*, in which are two small symmetrical sclerites ; above this is a small triangular space, part of the *epistoma;* in front of it you will see two small pointed processes of the mandible meeting in the middle line and articulating with the epistoma by a membrane throughout their whole length. On the outer hinder portion of the mandible, diagonally opposite the pointed process, you find a large pointed peg, which fits into a corresponding socket at the base of the epimeron which is here specially strengthened and calcified. On examining the endoskeleton you will find this point specially supported by stout transverse stays or apodemes, reaching from side to side of the cephalo-thoracic cavity. On the diagonal line joining this pivot with the anterior pointed process the mandible rotates.

The whole of this large rounded piece is the coxopodite. Close to the origin of the anterior tooth-like process is a three-jointed palp. The proximal segment represents the basipodite, the distal two, the endopodite. This we learn from a comparative study of certain lower Crustaceæ, in whom we find the basal joint of the palp bearing both endopodite and exopodite. In the dried skeleton the calcified tendons of the adductor muscles remain attached to the mandibles.

We have already seen a small portion of the ventral surface of the epistome. In front it is reflected dorsally on itself so that the whole is a flattened cone which forms

part of the anterior wall of the head. The epistome is homologically the sternum of the antennary somite, but in this case owing to its reflection it also forms part of the dorsal surface of the head.

To understand the structure of the antenna, you should compare it with that of the Prawn or the Cray-fish. In these latter animals you at once recognise the homologue of the protopodite (here called the *protocerite* from the Greek *keras*, a horn or feeler), with a short *coxocerite*, on the ventral surface of which is a small nipple-like projection perforated by an opening. This opening you find on dissection leads into the duct of the kidney or "green gland." Then you have an obvious *basicerite*, to which are articulated an *exocerite* in the form of a scale or flat plate, very large indeed in the Prawn. You will readily recognise in the rest of the long feeler an *endocerite* with two large basal segments and a long annulated terminal portion or *flagellum* (Latin, a whip).

In Panulirus you find no trace of the exocerite. You find a very long annulated feeler, sometimes a yard long, with apparently only three large basal joints. The two distal belong to the endocerite. The first movable joint has no opening for the green gland. This opening you will find on each side on a prominent little nipple near the outer angle of the large, somewhat triangular plate in front of the epistoma. You find dorsally, behind the antennules and in front of the eye, a large plate which you do not find in the Lobster Cray-fish or Prawn. Hence you are driven to the conclusion that the coxocerites of the two antennæ are firmly fused together and that these two plates represent the dorsal

and ventral surface of the united coxocerites ; therefore the first movable joint is the basicerite.

The antennules are the only appendages not built on the biramous plan. The stem you will note, consists of three cylindrical segments, which therefore do not correspond to the pieces of the protopodite, only two in all the other appendages.

The basal segment is the largest. There are two rows of setæ on its inner and dorsal surfaces. At the proximal end of the dorsal surface is seen the opening of the *statocyst.* Both filaments are annulated and much longer in the Indian than in the European members of the family. The inner filament is the longer.

To see the statocyst cut away the ventral portion of the basal joint of the antennule ; among the muscles you will find a small translucent sac. Dissect it out ; open it and examine with a low power. Observe a quantity of sand or grit, the *otoliths*. (Gr. *oto*, ear : *lithos*, stone). The lining of the sac bears a large number of bristles of varying length which are in continuity with the fibres of the auditory nerve.

The statocyst has, for a long time, been called the auditory sac, and it is probably the organ of hearing. It certainly has another function, that of *orientation*, as was proved by the following experiment.

At each ecdysis the cuticular lining of the statocyst with its otoliths is shed with the rest of the cuticle. When the new cuticle has become sclerosed the Crustacean buries his antennules in the sand to obtain a fresh supply of otoliths.

An ingenious experimenter took some Prawns at the moulting period and placed them in a tank where fine steel

filings were substituted for sand. The Prawns filled their statocysts with these filings. On removing them to an ordinary tank and placing a magnet near the statocysts, the Prawns changed their position in obedience to the magnet under the delusion that the steel particles were acted on by gravitation, the only force in their previous experience capable of altering the position of the otoliths!

The eye-stalks or *ophthalmites* have each two segments movable on one another. They are articulated to a median oval membranous space which looks directly upward. In this membrane are two small median sclerites, one in front of, the other behind the insertion of the eye-stalks. Those who claim an ophthalmic somite would call these the ophthalmic sternum and tergum respectively. They are sometimes united to form a single piece.

Circulatory Organs.

To examine the heart and greater vessels cut with stout scissors along the outer side of each branchio-cardiac groove. Join these cuts by a transverse one along the cervical groove. Remove the calcified portion. Note the underlying skin spotted with red and yellow pigment. Remove this skin carefully, and you will have opened into a large cavity filled with blood, the *pericardial sinus* (Gr. *peri*, around, *kardia*, the heart).

In this sinus lies the heart which will be found beating for some time in a recently killed animal. Its walls are thick, muscular and perforated by three pairs of openings, the *ostia* (Latin, *ostium*, a door), guarded by valves that admit the blood from the pericardium, but do not allow it to flow back when the heart contracts. Two of these ostia

can be seen on the dorsum of the heart, the others are on the lateral and ventral aspects and can be seen better on further dissection.

If desired the blood vessels may be injected with thin Plaster of Paris coloured with Prussian blue or carmine inserting the nozzle of the syringe into one of the ostia. The injection should be done slowly.

From the front of the heart a median *ophthalmic artery* is seen to run forward over the stomach to supply the ophthalmites and anterior part of the head. On each side of the ophthalmic is an *antennary artery* which passes forward to supply the green gland, antennæ, antennules, etc., of its own side. A little below and external to the antennary arteries are the pair of *hepatic arteries* which supply the digestive gland. Posteriorly the heart gives off a single large median vessel which, almost immediately, divides into a large *dorsal abdominal artery* which runs backwards above the intestine to supply it and the dorsal muscles, and a median *sternal artery* which runs directly downwards, sometimes to the right, more often to the left of the hind gut to enter the sternal canal. After passing through an opening in the large thoracic ganglion, it divides into two branches, one to run forward below the nerve cord and give off branches to the legs, jaws and neighbouring structures : the other to run directly backward beneath the nerve cord and supply the abdominal appendages and ventral muscles.

All these arteries divide in the tissues they supply into smaller and smaller arteries till finally they become *capillaries* (Latin, *capillares*, hair-like) microscopic in size.

In the Vertebrates, as you are aware, the capillaries

unite to form small veins, which by further union become progressively larger and return the blood to the heart. In the Arthropods this is not the case, with the exception of those in the gills, the capillaries terminate by open mouths and allow the blood to pass into large spaces between the viscera and muscles, known as *blood-sinuses* (Latin *sinus*, a fold of a garment, a pouch or a bag). These sinuses all eventually communicate with a large median longitudinal passage, the *sternal sinus*, in which the nerve cord and the two branches of the sternal artery lie. In the thorax the sternal sinus sends to each gill a vessel, which runs up the outer side of the gill-stem as an *afferent* (Latin *affere*, to bring to) *gill vessel*. In the gill the blood is only separated from the water by a thin diffusible membrane, so that an interchange of gases between the blood and the water readily takes place. Carbonic acid is given off, oxygen is taken in, and the purified blood is brought back by an *efferent* (Latin *effere*, to carry away from) vessel or vein on the inner side of the gill-stem. The efferent veins from the twenty-one gills unite into six larger vessels, the *branchio-pericardiac canals*, which pour the blood into the pericardiac sinus, whence it enters the heart during diastole and so the circulation is completed.

The efferent and branchio-pericardiac vessels can readily be injected with ink from a finely pointed medicine dropper, by cutting across the base of a gill and injecting the inner vessel. The course of the circulation in these vessels may also be demonstrated by blowing in air from a blow pipe. The air can be seen to bubble into the pericardial sinus if the sinus be filled with water.

The General Relations of the Viscera.

Remove the carapace and the terga of the abdomen with the underlying integument. Also the extensor muscles of the abdomen.

Note the *alimentary canal*, a straight tube near the dorsal surface running the whole length of the body. Throughout the greater portion of its length it is brownish in colour and about as thick as a crow-quill. In front it is much enlarged to form the *stomach*, filling the greater part of the head. Below the "cardiac area" of the carapace you find the *heart*, a dirty white or slightly yellowish, somewhat translucent organ, lying dorsal and posteriorly to the stomach in the *pericardial cavity*. Note the dorsal *abdominal artery*, a translucent tube running from the posterior end of the heart along the dorsal surface of the hind gut, also the three arteries running from the anterior part of the heart.

The *gonads* (Gr. *gone*, seed or reproduction) or reproductive glands lying below a thin membrane, the floor of the pericardial sinus, and partly covered by the heart. They vary in size and colour with the seasons. In the male the testes, two long white masses, joined near the middle by a transverse median piece. In a full grown, lusty individual they extend up on each side of the stomach in front, and behind reach into the abdomen below and at the sides of the hind gut. In shape the united testes resemble an elongated H. They are white in colour and a little irregular in outline.

In the young female or in the adult out of the breeding season the *ovaries* are whitish in colour and in the same position as the testes in the male. They also consist of two

ong lateral lobes joined by a median bridge. In the breeding season they become very large, extending into the first abdominal somite and deepen in colour to a salmon shade or deep coral red.

The Genital Ducts.

In the male the *sperm ducts* or *vasa deferentia* (Latin for "discharging vessels") are a pair of chalky-white, very much convoluted tubes, arising from the lateral lobes of the testes posterior to the median bridge. The distal loop of each is much thickened and runs forward some distance before turning backwards and downwards to its opening on the coxopodite of the last walking leg. In the breeding season the terminal portion acts as a sperm receptacle and becomes of a lavender colour and greatly distended with the cheesy, almost solid semen. Its walls contain many muscular fibres and it is said to be protrusible through the very wide opening.

In the female the *oviducts* are short thin tubes which run from the outer margins of the ovaries directly outwards and downwards to their openings on the coxopodites of the third pair of legs. To see the oviduct the liver and ovary must be pressed over from the epimeron towards the middle line with the handle of the knife. The *digestive gland* or *hepato-pancreas*, commonly called the liver, is a large, soft, yellow mass which fills up nearly all the rest of the cephalothoracic cavity.

Except the oviducts all the above organs can be seen without further dissection than opening the cavity as described above.

You should also note, on each side of the stomach, the large adductor muscle of the mandible, the attachment of which to the carapace you have cut. Separate the mandibles from one another; then with forceps pull the cut end of the muscle and observe how the mandibles are adducted or brought together in the middle line.

The Alimentary System.

The jaw apparatus has already been described and the student will have noted that the jaws are all external to the oral opening and not, as in the Vertebrates, inside it.

The mandibles are very large even for a Crustacean. Lobsters, Prawns and Crabs have large forceps, by means of which they can crush and tear their food before swallowing it. Panulirus, not being thus gifted, has some compensation in the size and power of the mandibles.

The mouth, we saw, was flanked by the mandibles and bounded in front by the fleshy labrum, behind by the metastoma. It opens into a short wide gullet or *œsophagus*, running nearly vertically upwards to enter the large gizzard or stomach, which occupies the greater part of the head cavity.

We may here remind you that in the embryo of the higher animals the primitive gut or alimentary canal is lined by the inner of the three embryonic layers, the *hypoblast* or *endoderm*. The original opening into this gut becomes completely closed and it is only at a later stage that the mouth and anal openings are formed. They are formed by a dimpling or tucking in of the outer layer, the *epiblast* or *epiderm*, till it meets the hypoblast, and an opening is

made where they touch. This tucking in or invagination is very shallow in most animals, much the greater portion of the digestive canal being lined by the hypoblast, only a very short distance inside the mouth and anus by epiderm. In other words, the adult canal is mainly a development of the primitive gut.

In the Arthropods we have a striking contrast. The dimples in front and behind, known respectively as the *stomodœum* (Gr. *stoma*, mouth, *odaion*, a passage) and *proctodœum* (Gr. *proktos*, vent, anus) become deeper and deeper, till instead of being mere pits they form long tubes that eventually meet the very short primitive gut or *mesenteron* (Gr. *mesos*, middle ; *enteron*, gut).

In Panulirus this mesenteron is less than a twentieth of the whole length of the alimentary canal. The œsophagus and stomach are formed from the stomodæum ; the whole of the abdominal and the greater part of the thoracic gut from the proctodæum. All the epidermis we have yet studied in Panulirus, both of the outer integument and of the apodemes, is covered with a chitinous cuticle. That lining the fore- and hind- gut is no exception, and is in parts calcified to form stout teeth and plates.

The stomach is divided into a dilated anterior or *cardiac* portion and a smaller, posterior, *pyloric* portion (Gr. *pylorus*, a gate-keeper or durwan). In man and other Mammals the gullet enters the stomach just after it has passed through the diaphragm in a position quite close to the heart. Hence as anatomy was first studied in the mammals, anatomists came to call the gullet end of the stomach the " cardiac " end. Later the name was continued in this sense

in describing any stomach. We need not point out that in Panulirus the " cardiac " end of the stomach is that furthest from the heart.

The chitinous lining is thick. Its calcified portions are called ossicles. They support three large and two smaller teeth, which by the action of the muscles attached to the ossicles crush and tear the food. The whole apparatus is commonly called the " gastric mill."

The stomach and intestine should be removed, emptied of their contents and boiled for a few minutes in a solution of caustic potash or soda. This will remove all muscular and connective tissue, leaving the chitinous structures only. Wash in water and open with scissors along the mid ventral line.

You will notice externally a pouch on the dorsal surface, between the pyloric and cardiac regions. Two white T-shaped calcifications will be seen, the legs of the Ts meeting at the bottom of the pouch. The cross bars of the Ts are placed transversely on the top of the cardiac and pyloric walls of the pouch respectively ; they may therefore be called the *cardiac* and *pyloric ossicles.* The tail of the anterior, larger T is called the *urocardiac* ossicle (Gr. *oura*, a tail) ; of the posterior T, the *prepyloric* on account of its position. These four pieces are movably articulated with one another. The prepyloric ossicle terminates ventrally in a strong yellow *median tooth*, which curves round the end of the urocardiac ossicle where these two legs of the Ts articulate.

From the outer ends of the transverse cardiac ossicle a *plerygocardiac* (Gr. *pteryx, plerygos*, a wing) ossicle runs

backwards and downwards on each side along the margin of the pouch referred to above. From the end of the pyloric ossicle on each side runs down to meet the pterygocardiac another broader ossicle, the *zygocardiac* (Gr. *zygon*, a yoke or crossbar), the ventral portion of which appears in the interior of the stomach as a rough file-like surface and in front terminates in a large curved yellow *lateral tooth.*

Below the lateral tooth on each side is found a small pointed tooth borne on an ossicle, the inner aspect of which is setose. There are other smaller ossicles in the stomach, but the above are the most important.

The transverse ossicles are acted on by muscles arising from the carapace in front and behind, as well as by muscles passing between them, which by their alternate action cause the teeth to clash together and again separate so as to thoroughly chew the food.

The passage from the cardiac to the pyloric chamber is narrowed by lateral folds and a large tongue-like valve covered with hairs on the ventral surface ; further back the pylorus is narrowed to a mere three-rayed chink, by the pushing in of its roof and the presence of cushions on its sides, the whole being covered with hairs through which only very finely chewed food can filter. With the pylorus the cuticular lining ends, and the food passes into the mid-gut, the only part of the canal lined with cells of hypoblastic origin.

These cells are secretory in character and continuous with those lining the two hepatic ducts which are seen opening on the floor of the mid-gut. The large solid-looking

yellow liver is in fact a tubular diverticulum or off-shoot of the mid-gut, which in the earliest embryonic condition is only a small pouch or tube on each side, but later on branches into an immense number of short blind tubes or *cæca* (Latin blind), which being closely packed together form the apparently solid mass of the liver, or hepato-pancreas. The cells are of two kinds, *liver-cells* containing yellow oil globules and *ferment cells* which produce the digestive secretion.

The secretion is a slightly acid, yellowish fluid, containing many oil-globules, and possesses the power of—

(*a*) converting proteids into peptones,

(*b*) turning starch into sugar,

(*c*) emulsifying fats.

The short mid-gut is followed by the straight hind-gut or proctodæum, which as already pointed out is lined with cuticle, which forms a number of longitudinal ridges set with small papillæ. The hind-gut opens on the ventral surface of the telson by a longitudinal slit, the anus.

The Excretory Organs.

The nitrogenous waste of the body is got rid of from the blood by the *nephridia* (Gr. *nephros*, kidney), a pair of "green-glands" whose apertures we have already seen on the ventral side of the basal joints of the antennæ.

Insert a bristle into this opening. You will find it enters a delicate thin walled sac or *bladder*, into which the

secreting portion, a coiled tube lined with epithelium, discharges. The glands are of a light greenish-yellow colour and lie in the extreme anterior part of the head. The stomach should be pushed back a little to see them.

The Nervous System.

After examining the heart, alimentary canal and reproductive system, the gut should be cut across about its middle and each end turned aside. The abdominal muscles should be carefully removed, when the nerve cord will be exposed lying in the middle line close to the abdominal sterna. The thoracic portion is enclosed in the central canal or tunnel, formed by the endophragmal skeleton which should be removed by forceps and scissors. The brain is seen in front of the œsophagus close to the origin of the ophthalmites.

When compared with other arthropods, the nervous system of Panulirus presents a very interesting study with many useful lessons on the subject of development and the origin of species.

In the Earthworm you have seen a long nerve cord stretching throughout the length of the body with a small thickening in each somite, which from its likeness to a knot on the cord is called a *ganglion*—Greek for a knot. You learned that this cord and its knots were originally a pair placed side by side, but have become enclosed in a common sheath so as to appear single. The microscope shows that in the worm the structure of cord and knot is much alike, both containing nerve-cells and nerve fibres, but in different proportions.

In the Arthropods we have a specialisation of structure in accordance with a differentiation of function. We have a series of ganglia which alone contain nerve cells the

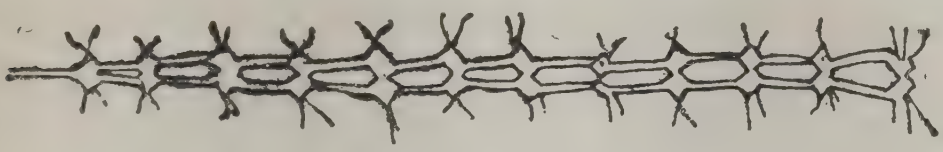


Fig. 27.

Nervous System of Sandhopper.

function of which is to originate or translate nervous impulses, while in the connecting cords we have only nerve fibres whose function is simply to *transmit* impulses. Roughly the ganglia may be compared to the receivers and generators of a telegraphic apparatus, the cords, to the wires.

It we take one of the lower Crustaceæ such as a Sandhopper, we find it has a "brain" or *suptra-æsophageal ganglia*, to supply the organs of special sense in the preoral region, and in each segment behind the mouth we find a double cord with double ganglia lying side by side in each somite. The same regular metameric arrangement we found in the young earth-worm.

In the higher Crustaceæ we find a pair of ganglia in each segment, but they have coalesced to form a median mass. The connectives have approached one another in the middle line, but a separation can still be seen in the cephalo-thoracic region.

In the Lobster we find a brain in front of the gullet; two connective nerves pass back on each side of the gullet to join a large ganglionic mass which we find is the united ganglia of the mandibular, the two maxillary, and the three

maxillipedary somites and supplies all six pairs of jaws and foot-jaws with nerves. A double nerve connective runs backwards to unite five other ganglia, one for each of the

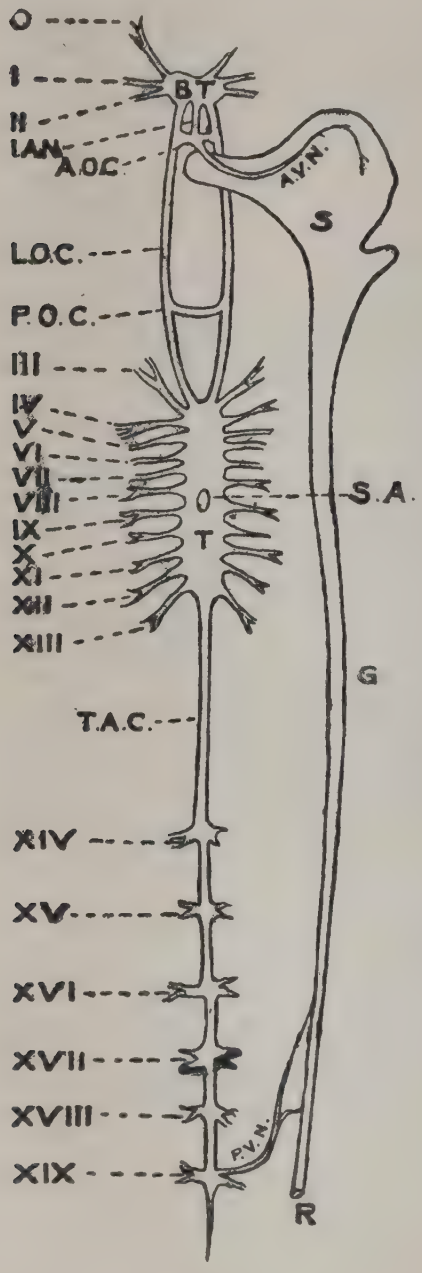


Fig. 28.

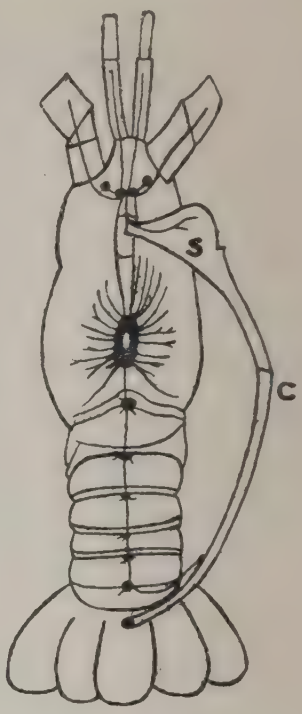


Fig. 29.

Fig. 28.—NERVOUS SYSTEM OF PANULIRUS.

O = Ophthalmic nerve.
I = Antennulary ,,
II = Antennary ,,
III = Mandibulary ,,
IV to XIX = Nerves to Segments.
BR = Brain.
T = Thoracic ganglion.
A V N = Anterior visceral nerve.
A N = Median root of anterior visceral nerve.
A O C = Anterior œsophageal commissure.
L O C = Circum-œsophageal connective.
P O C = Post-œsophageal commissure.
T A C = Thoracico abdominal connective.
P V N = Posterior visceral nerve.
SA = Opening for sternal artery.
S = Stomach } turned aside.
G = Gut }

posterior five somites of the thorax, and supply the five pairs of walking legs.

In the abdomen we find six ganglia, one for each somite. The cord joining them requires very careful examination to discover if it is really a pair of strands.

In Panulirus the concentration is still further marked. The brain or supra-œsophageal ganglia form a large two-lobed mass close behind the eye-stalks. It sends out three pairs of large nerves, the ophthalmic, the antennulary and the antennary whose course is sufficiently described by their names. Posteriorly it sends a *para-æsophageal* (Gr. *para*, near, beside) connective on each side of the gullet to join a large elongated ganglionic mass on the floor of the thorax.

This represents eleven of the post-oral ganglia, those of the three jaw somites and all eight thoracic somites united together with little indication of their metameric segmentation beyond the fact that the nerves radiate out from it to the eleven pairs of appendages. There is a large opening in the centre of these united ganglia through which the sternal artery descends before it divides into its anterior and posterior branches.

In the abdomen we find a ganglion for each segment, the last supplying the telson and giving a *posterior visceral* nerve to the hind-gut.

In front, the stomach is supplied by an *anterior visceral* nerve which arises by three roots,—a median one from the posterior surface of the brain, and two which arise, one on each side, from the para-œsophageal connectives and run transversely in to meet one another and the median root and so form the visceral nerve. The lateral roots of the nerve

meeting in front of the gullet are sometimes called the *anterior commissure.* Behind the gullet and in front of the thoracic ganglion is another transverse commissure, called the posterior.

In the Crabs, which are a higher race than Panulirus we find a still further concentration of the nerves, all seventeen post-oral ganglia being united into a large central mass from which the nerves radiate like the spokes of a wheel.

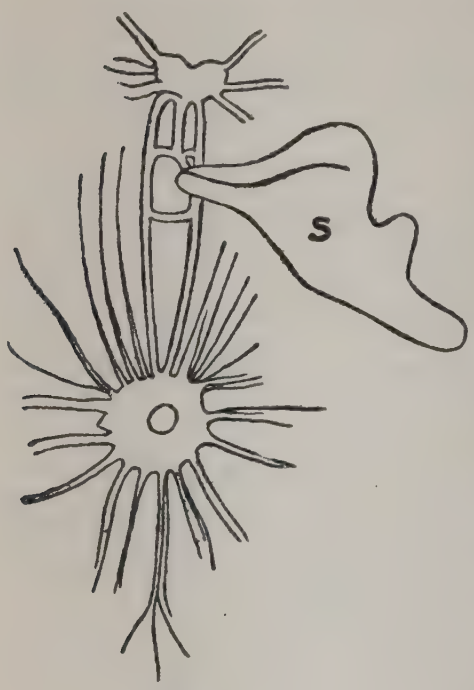


Fig. 30.

Fig. 30.—NERVOUS SYSTEM OF CRAB. Some crabs have no hole in the large ganglion, the sternal artery passing to one side.

In the very young Panulirus we find the nerve cord double and the thoracic ganglia separate, and it is only as development proceeds that they amalgamate. Later when you study the Mosquito you will have another instance of a similar coalescence of the ganglia. In the transparent Phantom larva you can actually watch the separate thoracic ganglia of the larva rapidly closing up and amalgamating in the pupa in the course of a few hours.

We have now learned that in the course of development of the individual Panulirus, the separate ganglia of the somites of the larva coalesce to form the large ganglion of the adult. We have also seen that in the "lower," earlier or more primitive type of Crustacean like the Sandhopper the ganglia of each somite are separate and paired as is also the connecting cord.

We have in the higher Lobster a further degree of concentration, the six ganglia behind the mouth having coalesced. In the Prawn, Palæmon, we have a stage intermediate between the Lobster and Panulirus, as the ganglia of the post-oral somites of the cephalothorax have all united, but the union is indicated by distinct indentations. Then above Panulirus, we have in the Crab all seventeen post-oral ganglia united into a single mass with practically no indication of metamerism, though in the larva it is distinct.

In Darwin's theory of the origin of species it is assumed that the higher types, such as the Crabs, have developed through past ages by a succession of stages through ancestors *resembling* or *common* to such *lower* animals as Panulirus, Prawn, Lobster and Sandhopper. In seeking to explain the origin of any species you will be greatly helped by the rule of which we have now seen an excellent example, that the *course of the development of an individual from the egg through its embryonic or larval stages up to that of the adult is an epitome of, and furnishes a clue to the history of the development of the species.*

The Compound Eye.

Place some fresh eye-stalks in a solution of 2% chromic and 2% nitric acid till the cells are fixed and the calcium salts dissolved. Make sections as accurately as possible in the long axis.

The eyes of Crustaceæ and of Insects are compound, that is composed of a large number of single eyes consisting of a clear vitreous central rod, one end of which is turned toward the external world while the inner portion is in contact with the light perceiving ends of the optic nerve fibres. Each of these eyes is isolated from its fellows by a pig-

mented tube or curtain, so that the only light which can reach the individual nerve-endings is a narrow pencil from objects in the straight line of the axis of the tube.

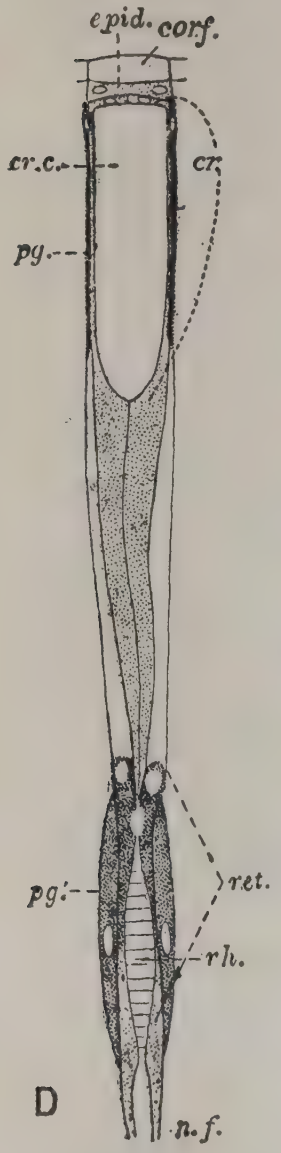


Fig. 31.

Each of these tubes with its contents is known as an *ommatidium* and there may be many thousands in the eye of an insect.

Peel off the *cornea* or cuticle covering the end of the eye-stalk. It is transparent and not calcified. Under the low power of the microscope it is seen to be marked out into a number of facets, some hexagonal, most square, each of which forms the outer surface of an ommatidium.

In longitudinal sections each facet is in many animals seen to be thickened at the centre to form a lens, but this is not noticeable in Panulirus. Below the cornea are two epidermal cells which have secreted the facet of the ommatidium. On the inner surface of these cells is an elongated transparent *crystalline cone,* surrounded by the four *crystal cells* which have produced it.

A single ommatidium of a compound eye.

Cor. f.—Corneal facet.
Cr.—Crystal cell.
Cr. c.—Crystalline cone.
Epid.—Epidermal cells.
N. F.—Nerve fibres.
Pg., Pg'.—Pigment cells.
Ret.—Retinula cell.
Rh.—Rhabdome.

The inner end of the cone is continuous with a spindle-shaped *rhabdome*, composed of a number of *rhabdomeres* (Gr. *meros*, a part). The rhabdome is surrounded by the *retinula*, (Lat., a little retina) a group of elongated cells which are in continuity with the fibres of the optic nerve. Each retinula is closely invested with dark pigment to isolate it from its neighbours. The distal portions of the cones also are separated from one another by cells containing some pigment.

The Reproductive Organs.

These have been already described with the topographical anatomy of the cephalo-thorax. It should be further noted that the gonads are hollow organs continuous with their ducts. You have seen in the Earth-worm, Frog and Rabbit types, that the ova are discharged into the cœlom and taken thence to the exterior by their ducts.

You have seen in Panulirus the body-cavity is not lined with epithelium as in these three types, but is continuous with the cavity of the blood-vessels. It is therefore not homologous with the cœlom, and may be called the *hæmocæle* (Gr. *haima*, blood, *koiloma*, a cavity).

The homologue of the cœlom in Panulirus is to be found n the cavity of the gonads and of the green glands.

In some of the segmented worms, we find the nephridia utilised for the discharge of the generative products, ova and spermatozoa. It is a characteristic of cœlomate animals that both the renal and reproductive organs are derived from the epithelium of the cœlom.

It is therefore not surprising when we find such distinct evidence of serial homology between the gonads and

nephridia in the sea worms, to find a certain homology between the green glands and the gonads of Panulirus, such as their cavities representing the cœlom and their ducts opening in homologous situations, the basal joints of appendages.

Development.

The female lays an enormous number of coral-coloured eggs, probably about a lakh each season. The egg is a single large cell containing in addition to its nucleus and nucleolus a large amount of yolk granules. After fertilisation by the spermatozoon, segmentation commences. In many animals segmentation begins by the complete division of the cell including the yolk, into two new cells. This is known as *complete* division.

In Panulirus as in most Arthropods segmentation is *incomplete*. The nucleus divides and subdivides repeatedly till we have a large number of nuclei, the cytoplasm and yolk not being divided up into cells. These nuclei all approach the surface, and later with the cytoplasm around them, give rise to a *germinal layer* of cells surrounding the yolk. This central yolk forms a number of cones, the base of each being applied to the inner aspect of a germinal cell. The whole embryo is now a hollow bag, formed of a single layer of cells known as the *blastoderm* (Gr. *blaste*, a bud, sprout or development, *derma*, a skin or layer) its cavity stuffed with nutrient material.

At one pole of the blastoderm an oval patch the *germinal disc*, is formed by a thickening of the layer of cells. At one end of the disc a pitting or dimpling takes place and gradually deepens to form a small wide-mouthed pouch.

This stage is known as the *gastrula*, (Latin, a little belly) and may be illustrated by pressing in one pole of a soft tennis ball.

This pouch the *primitive gut* or *archenteron* (Gr. *arche*, origin, primitive state, *enteron*, gut) continues to deepen and its mouth to contract till we get a completely closed sac.

The cells lining the primitive gut are known as the *hypoblast* or *endoderm* (Gr. *hypo*, under, *endo*, inner). The remaining cells of the blastoderm are the *epiblast* or *epiderm* (Gr. *epi*, above) from which is eventually developed the epidermis of the integument, of the fore-gut, of the hind-gut and the nerve system. A mass of cells appears between the hypoblast and epiblast near the blastopore, probably derived from the former; from it the muscles, connective tissues, heart, vessels, renal and reproductive organs are developed. It is called the *mesoblast* (Gr. *mesos*, middle).

In front of the blastopore, before it closes an elevation appears which lengthens in a forward direction. This is the rudimentary abdomen. In front of this again a pair of flatter elevations appear, one on each side of the middle line, called the *head lobes*. A median linear depression appears on the surface of the epiblast between these three elevations. Near its centre the groove deepens into a tubular ingrowth, the stomodæum, as already described. The primitive hind-gut arises in a similar manner on the abdominal papilla. A considerable time elapses before the partitions between the three portions of the gut disappear. The appendages appear as symmetrical pairs of buds of the

epiblast and mesoblast. Those of the antennules, antennæ and mandibles appear early. The eye-stalks appear later as outgrowths of the head lobes.

The epiblast on each side of the median ventral groove thickens in two longitudinal strands to form the double nerve chain, which later severs its connection with the tegumentary epiderm.

The eggs of many Crustaceæ, for instance Penæus, one of the Prawns, are hatched in an elementary stage with only the three anterior pairs of appendages, which become very large and are used in swimming. This is known as the Nauplius stage. In Panulirus as in Lobsters, Crayfish, the Prawn, Palæmon, and most of the other *Macrura* (Gr. longtails) this stage is passed inside the egg.

Owing to the fact that the larvæ of Panulirus are inhabitants of the open sea, the full course of their development has not been studied. Only recently it has been recognised that the little *Phyllosoma* (Gr. *phyllon*, a leaf, *soma* body) is the larva of Panulirus or its near relatives. These larvæ were formerly thought to be a separate genus and are popularly known as " Glass-Crabs."

Both the scientific and popular names are very descriptive, as the animal is extremely flattened and the greater part of its body consists of two large transparent discs resembling small watch glasses.

These discs represent the carapace. The anterior corresponding to the cephalic portion, is oval or nearly circular and covers the stomach, liver and head appendages. The posterior is the thoracic region : it contains the heart and intestine, and bears the eight thoracic appendages, which it

is interesting to note have both endopodite and exopodite at this stage. In earlier specimens the first maxilliped and last walking leg are rudimentary. The junction of the two

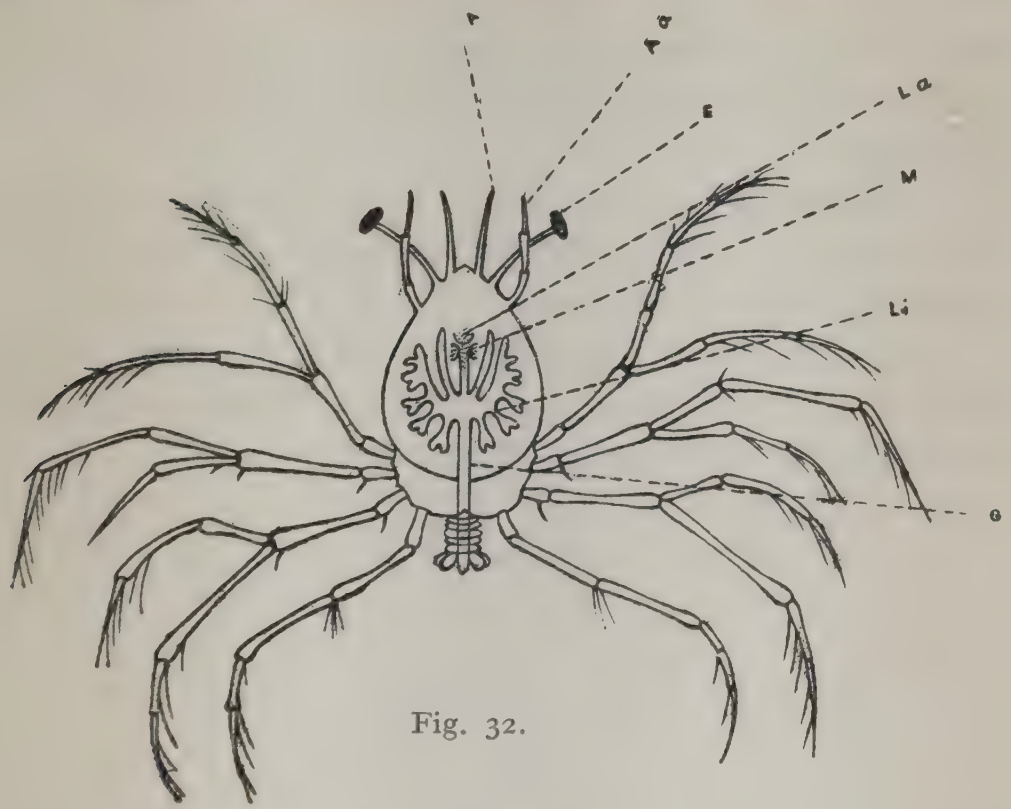


Fig. 32.

Fig. 32.—PHYLLOSOME. × 8.

A = Antennule. *Aa* = Antenna. *E* = Eye. *La* = Labrum. *M* = Mandible *Li* = Liver. *G* = Gut.

discs is the cervical groove in which the scaphognathite can be seen moving.

The eyestalks are of great length ; they, the antennules and the antennæ are all borne on the anterior margin of the carapace. You will note the gradual shifting of the position of the eyes from the ventral surface of the embryo in the egg, to the anterior margin in the phyllosome and finally to the dorsal surface of the adult.

The liver can be seen through the transparent disc as a more or less branched diverticulum of the mid-gut.

The abdomen is very small ; you can see six pairs of small appendages, the pair of the first somite disappearing before the adult condition is reached. In most phyllosomes the posterior margin of the hinder disc is notched to receive the abdomen.

The nerve cord is double ; in the specimen sketched there were six distinct thoracic ganglia. The reproductive organs cannot be recognized.

The phyllosome stage lasts a month or two, during which time it moults repeatedly ; at the last moult the discs are replaced by a carapace of the adult pattern.

THE COCKROACH.

Place before you a Cockroach and a Mosquito and compare them with Panulirus. You will notice that the bodies of all three are bilaterally symmetrical and divided from in front backwards into distinct segments or metameres, some of which bear a pair of appendages composed of distinct segments united by movable joints. These three external characteristics unite all three animals in the sub-kingdom or Phylum, *Arthropoda.**

Panulirus possesses two pairs of antennæ, and several appendages of the biramous type and breathes by gills. These are the characteristics of the class, *Crustacea.* The Cockroach and Mosquito on the other hand possess only one pair of antennæ, their walking legs are six in number and never biramous, they breathe by means of tracheæ and their body is made up of three readily distinguished regions, head, thorax and abdomen. They also, as a rule, possess wings. These are the general characteristics of the class, *Insecta.* †

About a thousand species of Cockroach have been described. Of these at least half a dozen have attached themselves specially to the dwellings of man and so usurped the title, "Domestic." The Cockroach rivals the Englishman in his travelling and colonising propensities, so that a species

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* Gr. *arthros,* joint ; *pous-podos,* foot.

† Latin, *Insectus,* cut into : from the body being partite into head, thorax and abdomen.

that is common in a certain city or country to-day, may in a few years be outnumbered by a new immigrant. It is said that England was free from the domestic Cockroaches till the reign of Elizabeth when *Stylopyga orientalis*, a native of India, invaded and colonised Europe. A little later *Periplaneta americana* arrived in the ships of Sir Francis Drake and others from America. Of late there has been a German invasion of Bombay by a third species, *Phyllodromia germanica*.

In Bombay City we have all three of these insects firmly settled in much larger numbers than in any English city. Perhaps the most common is *P. americana*. There is also a large Australian and three or four smaller species in the city, while in the jungle may be found a really handsome Cockroach, the piebald *Corydia*, with black velvety wing-cases marked with orange or white spots, the terga and under surface being of a bright orange color.

As either the American or Oriental Cockroach can be readily obtained and both are of a large size for dissection, the following description will deal with these species.

Cockroaches, like most thieves, are nocturnal in their habits, hiding in the day time and sallying forth at night in search of food. They are almost omnivorous, nothing animal or vegetable, even boots, saddlery and books comes amiss to their crop. They are often erroneously called "Black Beetles" by lower class Europeans, but they are not black, and they are not beetles. Beetles belong to quite another order of Insects and can be readily distinguished as their wing-covers do not over-lap like those of the Cockroach but when folded their inner edges meet accurately together

in the middle line. In their development Beetles pass through a grub or larva and a pupa stage which the Cockroach order, Orthoptera, does not do.

Catch some Cockroaches and place them in a large glass vessel with some food to watch their movements and manner of feeding. Note how he uses his long feelers or antennæ and also the palps of the maxillæ to examine the surface over which he moves. Watch him eating and notice how the mandibles and maxillæ work to and from the middle line like those of Panulirus and not up and down, like the jaws of a Rabbit or Frog.

Observe the movements of the abdomen, how it is alternately expanded and contracted from above downwards. These are the movements of respiration by which air is alternately drawn in and expelled through ten pairs of openings known as stigmata, on the sides of the thorax and abdomen.

To kill the Cockroach pour a few drops of chloroform, petrol or benzol on it.

Observe that the body is covered with a cuticle made of chitin, which in definite situations is hardened into sclerites like those of Panulirus except that they are not calcified. In the abdomen we can count ten metameres, each of which is covered dorsally by a *tergum* and ventrally by a *sternum*, which overlap one another from before backwards like the tiles of a roof. Between each of these sclerites the cuticle is soft and allows of considerable movement in the dorso-ventral plane. Laterally between the edges of the terga and sterna the cuticle is soft and known as the *pleuron*. You will note that this is not homologous with the pleura of Panulirus where this name is given to the lateral margins of the terga.

On stretching the abdomen and bending it to one side you will be able to see the *stigmata* or respiratory openings in the pleura, eight on each side of the abdomen, two on the thorax, one behind, the other in front of the mesothorax.

Of the terga you will note that the last, the tenth, is prolonged backwards as a thin plate deeply notched behind. In the male *S. orientalis* all the terga can be seen without dissection, but in the female of this species and in both sexes of *P. americana*, the eighth and ninth are so telescoped forward as to be completely overlapped by the seventh. By pulling the tenth backwards with forceps the eighth and ninth can be seen. On lifting up the tenth tergum the anus can be seen, flanked on each side by a sclerite called a *podical plate*. Some biologists regard this pair of plates as homologous with the tergum of an eleventh segment. A pair of many-jointed feelers, called the *cerci*, can be seen in both sexes projecting backwards from under the tenth tergum.

Of the sterna the first is rudimentary in both sexes. In the male nine are visible. To the posterior free margin of the ninth are attached a pair of slender unjointed, bristly *styles*, which are not found in the female. On cutting away the tenth tergum and the podical plates we expose the *gonapophyses*, a number of asymmetrical chitinous plates and hooks which represent processes of a tenth sternum and are used in copulation to hold and open the female genital aperture. You will note that the abdomen of the male is not so broad as that of the female.

In the female only seven sterna are visible externally, the posterior three being modified for sexual purposes and telescoped forward under cover of the seventh to form a geni-

tal pouch. The seventh is large and shaped like the bow of a boat, its posterior portion is split longitudinally into two thick chitinous halves, united by a thin flexible membrane which allows them to separate during copulation and the laying of the egg-case. The latter is often carried about for a considerable time protruding from the genital pouch.

The eighth and ninth somites are telescoped into the cavity of the seventh sternum, their terga are reduced to narrow bands ; the sternum of the eighth is a plate pierced by a vertical slit, the opening of the vagina ; the ninth is a small curved plate on which the spermatheca rests. Two pairs of gonapophyses, an anterior belonging to the eighth, a posterior bifid pair to the ninth somite, act as ovipositors and hold the egg capsule while it is being formed and hardened.

THE THORAX.

In all Insects the thorax is composed of three, and only three segments, named from in front backwards, prothorax, mesothorax and metathorax. These are covered dorsally by terga called pronotum, mesonotum and metanotum respectively. Observe that the pronotum which in the Mosquito is scarcely recognisable, is the largest of the three terga in the Cockroach and overlaps the head in front, and the mesonotum behind. To the margins of the mesonotum are attached the wing-covers or first pair of wings, which are much firmer than the second pair to which they act as covers for their protection when at rest. The second pair of wings which are those with which the insect flies, are attached to the metanotum. They are thin and flexible membranes, strengthened like the forewings by numerous radiating and cross

"veins" or nervures which act as supports like the ribs of an umbrella. When not in use the wings are folded up fan-wise under the wing covers.

The student must remember that these veins or nervures are not homologous with the veins or nerves of the vertebrates. They originate as channels through which the blood circulates and usually contain a trachea and a stiff rod or "rib."

In the female *Stylopyga orientalis* the wings are rudimentary. In the young of both sexes in all species, they are absent and only appear at the last moult. The wings are not true appendages: they are outgrowths of the skin covered by cuticle and may be regarded as homologous with the thoracic pleura or gill-covers of Panulirus. This homology can be readily recognised in the rudimentary wing-covers of the female Oriental Cockroach which are obviously extensions of the tergal margin.

The thoracic sterna being covered by the proximal joints of the legs do not need to be large or stout. The prosternum is small; in the male the mesosternum is partly, in the female, completely divided into lateral halves; the metasternum is completely divided in both sexes. As in Panulirus we find an endoskeleton formed by certain apodemes or ingrowths of the cuticle, so in the insect we find homologous ingrowths known as the *forks*, or Latin, *furca*. In some insects such as the Ants, we get three well developed *furca*. In the Cockroach the anterior is rudimentary or absent. The middle and posterior are somewhat T or Y shaped, the central notch supporting the nerve cord while the long arms afford attachment to muscles. These should be isolated

after the dissection is completed by boiling the skeleton in Liquor Potassæ. In the pleura of each thoracic segment can be recognised two sclerites, a dorsal *epimeron*, and a ventral *episternum*.

There are three, and only three pairs of legs in all insects, from which fact the class is sometimes called the Hexapoda (Greek, six legs). One pair is attached to each thoracic segment. Each leg is composed of a number of segments or podomeres, united by moveable joints. The proximal is stout, muscular and flattened. It is called the *coxa* (Lat. hip). The second, very small, is called the *trochanter* (Gr. top of the thigh). The third, long and muscular, is called the *femur* (Lat. thigh).

The fourth, long, thin and covered with spines is called the *tibia* (Lat. the shin).

Lastly the foot or *tarsus* (Lat. sole) composed of six segments provided on their ventral aspect with whitish bristly pads to enable the insect to retain a foothold on slippery surfaces. The last or distal joint of the tarsus bears a pair of claws between which is a pad called the *pulvillus*.

The narrow neck connecting the head with the thorax is covered with flexible chitin strengthened by seven brown sclerites. One of these is dorsal and almost divided into two by a median groove, so that it is sometimes described as two sclerites. Two are ventral, narrow, transverse bands. On each side are two larger oblique sclerites.

THE HEAD.

While the metamerism of the abdomen and thorax is very obvious it is not so easily recognised in the head, as the

exoskeleton is not divided into separate terga for each metamere of which it is composed. During the development of the embryo the segmentation is more evident so that most observers are agreed that the head is composed of at least six somites, namely,

1. One bearing the eyes, in front of the antennæ.
2. The antennary somite.
3. A premandibular somite which disappears during embryonic life.
4. Mandibular somite.
5. First maxillary somite.
6. Second maxillary somite.

A large smooth sclerite, the *epicranium*, covers the nape and vertex of the head. It is marked into lateral halves by a median suture which in front bifurcates like an inverted Y, each branch running downwards and outwards to a small white spot internal to the insertion of the antenna of its own side. The front of the head below this suture is known as the *clypeus*. To the lower margin of this is articulated a flap, the *labrum*, (Lat. upper lip) which forms the anterior wall of the mouth. Behind and below each eye is a sclerite known as the *gena* (Lat. cheek) or cheek-piece, which passes downward and covers the articulation of the mandible.

When the head is severed from the neck we find a large shield-shaped opening, the occipital foramen, bounded above and on each side by the epicranium which sends down processes with which the mandibles articulate. As in Panulirus we find certain *apodemes* forming an endoskeleton by an

ingrowing of the cuticle. From the lower margin of the occipital foramen one of these chitinous apodemes, the *tentorium*, grows in downwards and forwards, to form a ledge-like support for the brain.

Observe the large, black, somewhat kidney-shaped eyes, one on each side of the head. They are compound eyes with numerous hexagonal facets and resemble in their essential structure the eyes of Panulirus. Owing to the hardness of the chitin in the Cockroach it is easier to make sections from the eye of some large moth to see the histological structure. Also observe the small white dots near the inner margin of the insertion of the antennæ. These are called the *fenestræ* (Lat. windows). Their appearance is due to the overlying integument being transparent and allowing the white tissue below to be seen. It is doubtful what function they fulfil, but they are obviously homologous with the ocelli or simple eyes of many insects as they are replaced by true ocelli in the jungle Cockroach, *Corydia*.

The antennæ are attached by flexible membranes to the margins of sockets bounded, externally by the eyes, above by the epicranium and below by the clypeus. They are composed of from seventy to ninety segments, their surface marked by numerous small forward-pointing bristles. They act as feelers or special organs of touch. Some observers regard them as organs of smell and hearing also.

Observe that while Panulirus and most Crustaceæ possess two pairs of antennæ, no insect has more than one pair. In many insects, for instance, the Mosquito, the antennæ show characteristic sexual differentiation. In the Cockroach this is not at first sight so obvious, yet a careful examina-

tion shows that they are usually longer in the male and that in the female the third joint from the base is about twice as long as that in the male. See Fig. 33.

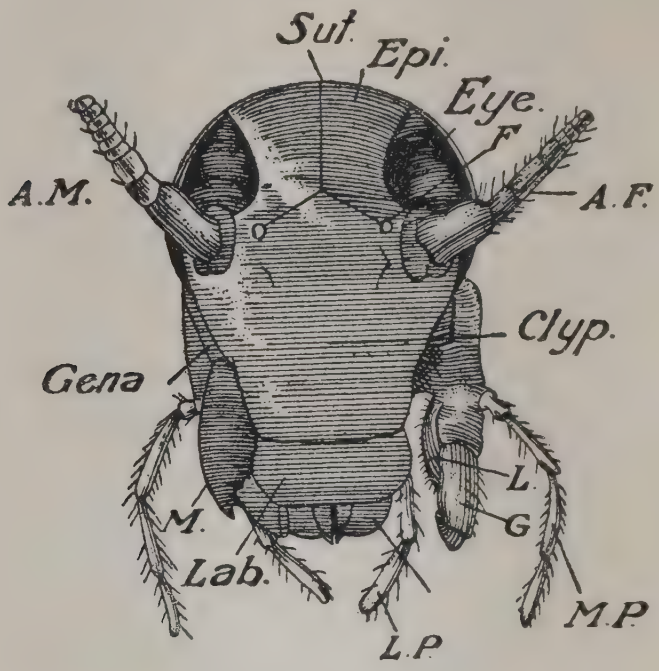

Fig. 33.

Diagram of head seen from in front.

Sut=suture; Epi=Epicranium; M= Mandible; G=galea; L=lacinia; Lab=labrum; L P=labial palp; M P=Maxillary palp; A F=Antenna showing female characters; A M=Antenna of male type; F=fenestra.

Fix a Cockroach, back downwards, with pins passed through the sides of the pronotum; over-extend the head on the neck so that its posterior surface looks upwards; keep it in this position by crossed pins. Pass one blade of a fine pair of forceps in front of the labium and grasp the latter as close to its attachment as you can; gently pull off the entire labium with the forceps aided by a few touches of the knife; avoid injuring the lingua; if the cuticle of the

ventral surface of the neck be peeled off with the labium, so much the better.

In the same manner remove the first maxillæ and mandibles in succession. They can be examined at once with a lens or may be preserved permanently in the following way.

Boil in solution of caustic potash to get rid of all muscle and other tissue except the chitin. Wash in water ; mount in glycerine ; ring with varnish. Or dry ; or dehydrate with alcohol ; pass through oil of cloves into Canada balsam. Mount the maxillæ and labium under a cover-glass. The mandibles may be simply attached by balsam to the slide as they are too thick to be kept under a cover-glass. The labrum, antennæ, legs, gonapophyses, furca and any other sclerite may be mounted in the same way.

The mandibles are a pair of stout unjointed jaws bearing six or seven teeth on their inner opposable surfaces. They articulate with the clypeus and the lower end of the epicranium. You will note that, unlike Panulirus and most Crustaceæ, the mandibles of an insect never bear palps.

Both pairs of maxillæ are constructed on the biramous plan though the homology of the several parts with those of a crustacean appendage must not be taken for granted.

Each first maxilla consists of a two jointed protopodite bearing a bifid endopodite and an external palp or exopodite.

The proximal joint, the *cardo* (Lat. a hinge) is horizontal and at right angles to the distal *stipes* (Lat. stalk). The inner division of the endopodite is a sharp-pointed blade,

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the *lacinia*, (Lat. a flap) bearing a number of stiff setæ on its inner margin. The outer, the *galea*, (Lat. helmet) is so called because it is hollowed at its distal end to form a cap which protects the point of the lacinia.

The exopodite is the five jointed maxillary palp.

The second maxillæ are formed of the same elements as the first, but the protopodites are united together in the middle line in all insects so as to form a *labium* or posterior lip.

The proximal joint, homologous with the cardines, is called the *sub-mentum*; the conjoined stipes, the *mentum*.* The endopodite consists of an inner *lacinia*, and an outer *paraglossa* which is serially homologous with the galea.

The two endopodites taken together are sometimes called the *ligula*.† The exopodite has only three joints and is usually called the *labial palp*; the projecting portion of the mentum to which it is attached is called the *palpiger*.

Before dissection of the internal organs the wings and legs should be cut off and the animal fixed, ventral surface downwards, to a cork sheet by passing pins through its lateral portions, taking care to avoid injury to any important organ, or preferably by imbedding the ventral surface in wax or paraffin. This is best done by pouring melted paraffin which can be made dark by mixing some lamp black with it, into a shallow dish such as a porcelain ointment-pot. In this case the coxæ may be left attached so as to "root" the animal firmly. The central portion of the wax can then be melted by touching with a heated iron; then hold

* Lat. chin.

† Lat. a little tongue, a strap.

the insect in position in the melted wax till it sets. Cut the terga and nota close to each side, carefully remove the

Fig. 34. Mandible.

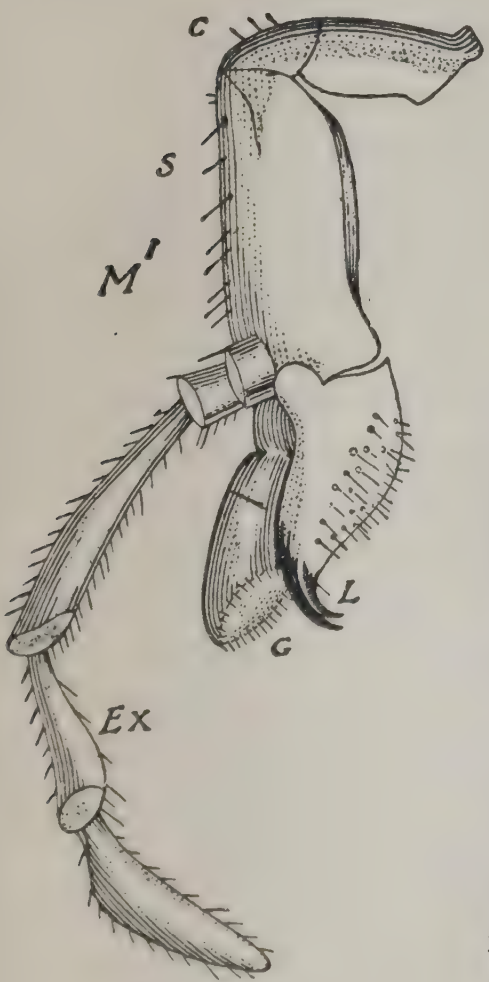

Fig. 35.
First Maxilla.
C=cardo ; Ex=palp ; G=galea.
L=lacinia ; S=stipes.

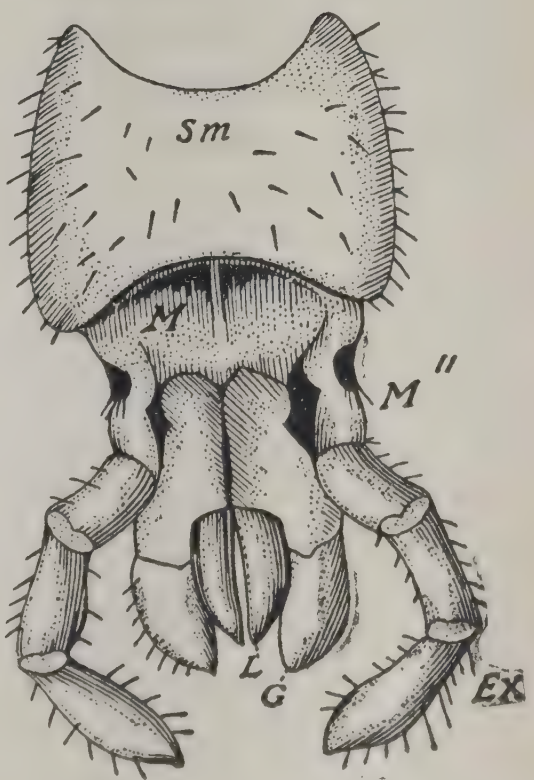

Fig. 36.
Labium.
Ex=palp ; G=paraglossa ; L=lacinia ; M=mentum ; Sm=submentum.

dorsal exoskeleton between your incisions, taking great care not to injure the underlying heart.

You have now exposed the body-cavity in which the viscera lie surrounded by the white *fat-body*. The insect's body-cavity like that of Panulirus and all Arthropods is not a cœlom but a hæmocoele* that is to say a blood-containing cavity in free communication with the open blood-vessels, so that all the internal organs are bathed in blood.

The heart can be seen pulsating in young Cockroaches, especially shortly after an ecdysis, before the cuticle has turned dark and opaque. It lies close below the terga in the middle line and is exposed at once when the latter are raised. It lies in a *pericardium* the floor of which is formed by a thin perforated membrane to the sides of which are attached delicate triangular *alary* muscles arranged metamerically. The apices of these alary muscles are attached to the under surface of the terga. As the pericardial membrane is arched when at rest, the contraction of these muscles will flatten it and so increase the size of the pericardial space into which blood will therefore be drawn from the body cavity. The openings of the heart are provided with valves to prevent the return of the blood from the heart.

The heart is a long, narrow muscular tube formed of a series of thirteen funnel shaped chambers, one for each thoracic and abdominal somite. The apex of each chamber opens into the base of the one in front of it. There is a valvular opening or *ostium* on each side of the base of each chamber. which allows the blood to enter from the pericardium but closes during the systole, so that the blood is driven from

* See page 129.

behind forward. The heart terminates in a narrow vessel on the dorsal surface of the œsophagus and gives off no lateral branches in any part of its course.

The fat-body is a branching mass of opaque white cells containing many small fat globules and urates or other excretory substances. It is abundantly supplied with tracheæ and fills the interstices of the body-cavity between the viscera.

Clean away with forceps, knife and scissors as much of the fat-body as you can. In India you will often find scattered in the fat-body numbers of translucent, oval, pearly bodies resembling the ova of the insect. These are parasitic worms, *Echinorrhynchus moniliformis*. Draw the alimentary canal to one side and clear it of fat-body and tracheæ by teasing with sharp-edged needles. Take care not to damage the salivary glands in front, or the Malpighian tubules and the reproductive organs behind. The student need not try at his first attempt to find the testes or vasa deferentia.

The alimentary canal of all insects is, like that of the Crustaceæ, remarkable for the length of both the stomodæum and the proctodæum as compared with the mesenteron.

In the study of embryology we learn that the cavity of the gastrula lined by the hypoblast becomes the archenteron or primary alimentary canal. The original opening into this cavity becomes obliterated, so that at one stage, the enteron is a completely closed sac.

In the epiblast, at each end of the body, a dimple forms which deepens till the epiblast meets the hypoblast, and finally the opposed portions becoming absorbed, the depressions become openings into the archenteron.

The anterior or oral depression is known as the STOMODÆUM (Greek: *stoma*, mouth; *odaion*, an entrance) or primitive fore-gut; the posterior is known as the PROCTODÆUM (Greek: *proctos*, anus) or primitive hind-gut.

In the vertebrates these depressions are comparatively shallow, so that only the mouth and the anus are lined by epiblast—in man and the rabbit, for instance, not one hundredth part of the length of the alimentary canal—all the remainder being lined by cells derived from the hypoblast.

In the Insect as well as in the Arthropods generally, only a relatively small proportion of the lining of the alimentary canal—the mesenteron or mid-gut—is derived from the hypoblast.

The invagination of the epiblast at both oral and anal extremities is very extensive, so that all those portions known as the fore-gut and the hind-gut are lined by epiblast.

The alimentary canal of the Cockroach is divided into the following regions:—

Foregut or Stomodæum	Buccal Cavity. Oesophagus. Crop. Gizzard or proventriculus.
Midgut or Mesenteron	Chylific Stomach.
Hindgut or Proctodæum	Ileum. Colon. Rectum.

The stomodæum is lined throughout with chitin continuous with that of the external surface. We have already seen the mouth to be bounded in front by the labrum, behind by the labium and on each side by mandible and first

maxilla. The posterior wall of the buccal cavity is raised into a fold, the tongue or hypopharynx. The buccal cavity leads into a narrow gullet or *œsophagus*, which passes between the anterior processes of the tentorium, through the nerve ring and occipital foramen, into the neck and thorax where it gradually widens into a thin-walled, capacious *crop* of an elongated pear-shape. Behind this comes the thick-walled muscular *gizzard* of a pear-shape with its broad end toward the crop, its narrow end projecting like a funnel into the mesenteron. A transverse section of the gizzard shows its cuticle raised into six longitudinal ridges or teeth of a dark brown color. Between these main ridges are several smaller elevations. Behind these teeth are six cushions covered with bristles which act as a strainer to the food.

The mesenteron is a narrow and short tube, the only part of the canal lined by endodermic epithelium. The *hepatic cæca* are seven or eight diverticula of the anterior end of the mid-gut also lined by endodermal cells.

The proctodæum is the coiled hinder portion of the gut lined throughout by chitin. The opening into the mesenteron takes place at a very late period in the life of many insects ; for instance in the larva of the Honey Bee we find the mesenteron for a long time terminates as a blind pouch. In this condition the hind-gut receives none of the food and can only act as the duct of the Malpighian tubes.

The anterior portion of the hind-gut is a short and narrow tube called the *ileum* (Lat. gut) into the commencement of which the Malpighian or excretory tubes open. The middle portion of the hind-gut is longer and wider and called the *colon ;* a constriction at its posterior end marks it off from

the *rectum*, the terminal portion of the gut which opens by the anus between the podical plates. Its wall is raised into six longitudinal ridges reminding us of the same condition in Panulirus. Slit up the alimentary canal and note the teeth, pads and bristles of the gizzard, its projection into the mesenteron, like the neck of an unspillable ink-pot, the openings of the hepatic cæca and the chitinous ridges of the rectum.

The salivary glands of the Cockroach are very large. On each side they consist of two white lobes about 6 to 8 mm. long, composed of numerous lobules united by ducts which join to form a main duct for each of the two lobes. These unite to form a single duct on each side which joins with its fellow below the sub-œsophageal ganglion into the common duct which opens on the floor of the mouth in the angle between the tongue and labium.

Between the lobes of the gland on each side are the salivary receptacles, two elongated sacs about 10 mm. in length, each provided with a duct. These ducts unite first with one another, and then with the common duct of the secretory portion of the glands. The glands and their receptacles lie along the sides of the œsophagus and crop as far as the first somite of the abdomen. They must be carefully dissected free of all fat-body from which they can be distinguished by their being more translucent than the opaque white fat-body.

The glands should be removed entire, fixed in picric acid, stained with carmine and mounted in balsam. The ducts resemble tracheæ in the spiral thickening of their chitinous lining.

The *Malpighian tubules* are organs for the excretion of nitrogenous waste in Insects. In the Cockroach they are very numerous, about sixty to eighty, so fine as to be just visible to the naked eye. They are usually of a yellowish

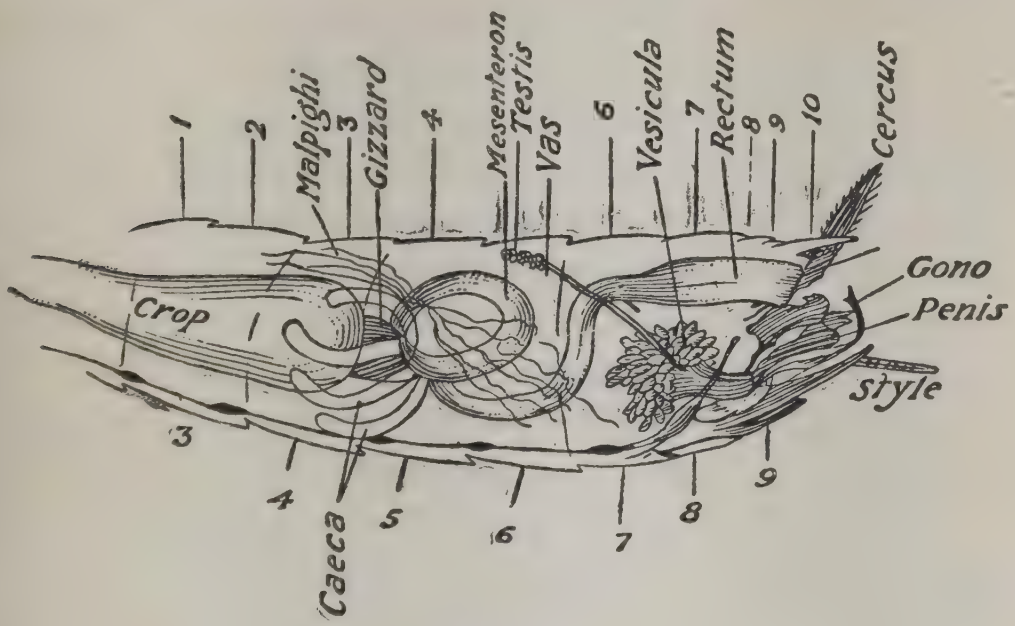

Fig. 37.

Abdomen of Male Cockroach.

green color, about an inch in length and extend throughout the whole of the fat-body of the abdomen. They originate as diverticula of the proctodæum, into the anterior end of which they open.

MALE REPRODUCTIVE ORGANS.

A young male should be selected and the *testes* sought for in the fat-body just below the fifth tergum of the abdomen. They are a pair of elongated glands, composed of a number of minute pearly vesicles attached to the vas deferens. They are not difficult to find though of small size and imbedded

in the fat-body from which they can be distinguished by their greater translucence and the pearly color of the vesicles. They may atrophy in old insects and it is then impossible to find them. The *vasa deferentia* are extremely fine tubes, finer than those of Perichæta, which run backwards and downwards to enter the *vesiculæ seminales.* These are simple oval sacs in the newly-hatched cockroach but later a large number of cæca develop so that in the adult the two vesiculæ together form a large snow-white tuft of a mushroom shape. The short stalk of this mushroom is the muscular *ejaculatory duct* which opens just below the anus and does not traverse the organ commonly called the penis which is imperforate.

Ventral to and usually to the left of the ejaculatory duct is a gland of unknown function, called either the *accessory* or *conglobate* gland. It is composed of a number of beaded tubes lined with epithelium which branch dichotomously and are enclosed in a common capsule to form a club-shaped mass. Its duct opens on one of the gonapophyses, shaped somewhat like a hunting spur.

The *gonapophyses* should be isolated and cleaned by boiling with caustic potash. They are asymmetrical. A long hook terminated like a crochet needle lies to the left, next to it is the imperforate *penis,* shaped somewhat like the human organ of that name, then several weird plates and hooks of different shapes.

FEMALE REPRODUCTIVE ORGANS.

Each of the two *ovaries* consists of eight tapering tubules which open into an oviduct. Each tube is about ten millimetres long and beaded in appearance owing to the ova

in different stages which distend it. The distal ova—those nearest to the oviduct—are the largest, those at the tapering end, the smallest. The smaller ova show a distinct nucleus and contain little or no yolk. As they enlarge and pass down the tubes, yolk gradually accumulates till the egg becomes so granular that the nucleus cannot be seen. The tapering ends of the tubes unite into a slender thread which passes upward and forward to anchor the ovaries in the fat-body.

The *oviducts* are short and unite to open by a short *vagina* on the eighth sternum into the genital pouch.

Behind the point of union of the oviducts is the *spermatheca*, a small flask-shaped sac with a coiled diverticulum given off from its duct which opens in the median line of the ninth sternum. To find this sac trace the nerve cord backward and you will find it close behind the last ganglion.

Two much-branched *colleterial* * or *cement glands* of a dead-white color, open behind the spermatheca by separate ducts close to the middle line. They secrete the substance of which the egg-case is formed. The left is usually larger than the right.

NERVOUS SYSTEM.

The nervous system of insects is on the same metameric plan of paired ganglia for each somite, united by double connectives, that we have seen in the Earthworm and Panulirus, but as in the latter, the plan is in parts obscured by coalescence of the ganglia. In the head we find the œsophagus surrounded by a thick irregular nerve-ring. To expose this, fix the head, anterior surface upwards, by passing a pin

* Greek, *kolle*, glue, cement.

through the upper part of the epicranium and another between the mandibles. Cut away the clypeus and the front

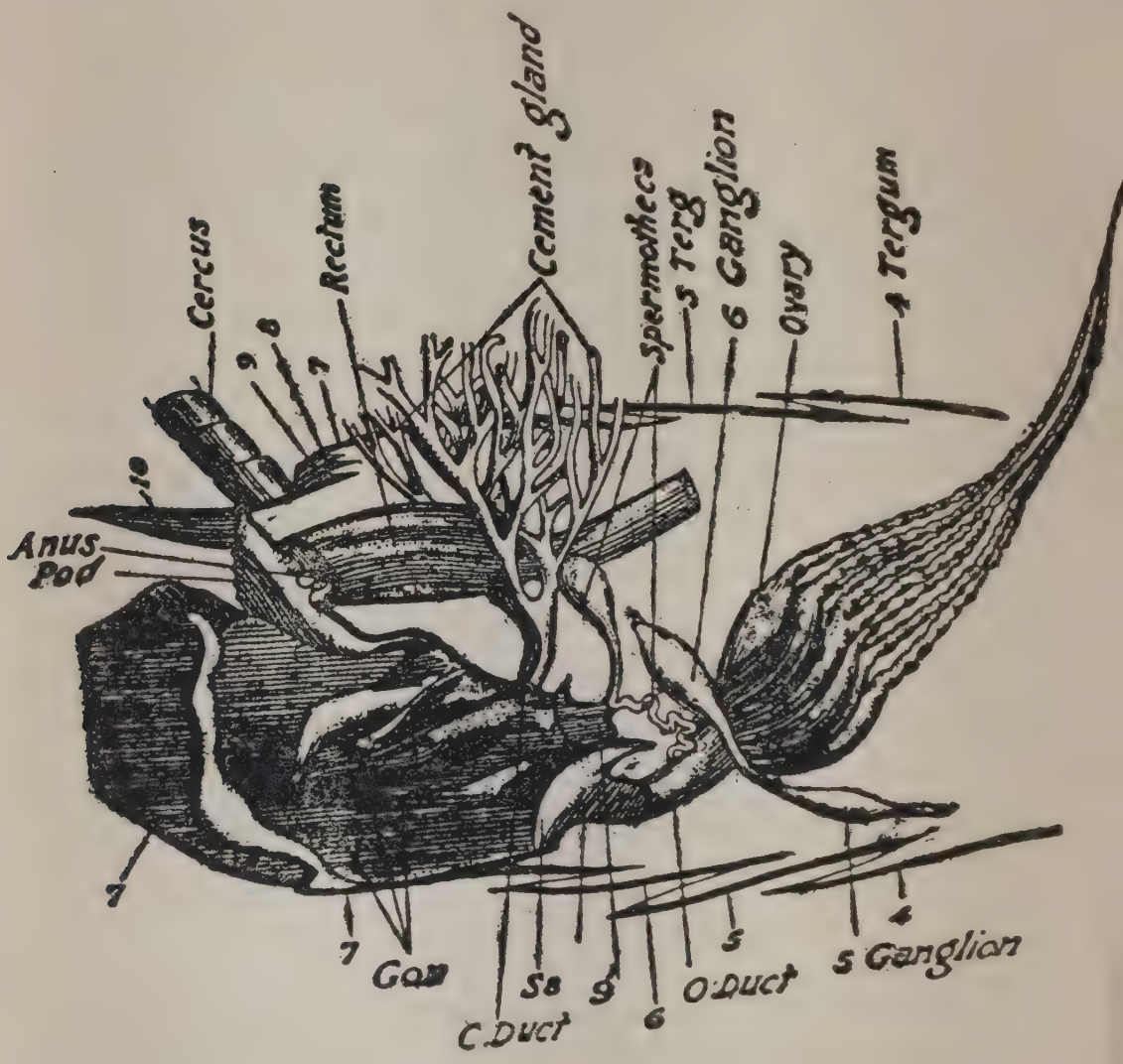

Fig. 38.

Reproductive Organs of Female Cockroach. (After Marshall and Hurst.)

of the epicranium with the point of a knife. Afterwards turn the head on one side and remove the gena, the mandible and part of the maxillæ.

A longitudinal median section should also be made with a razor through an insect well hardened in alcohol, to see the relations of the parts.

The *brain* or *supra-œsophageal ganglia* consists of a pair of two-lobed masses. Of these the upper lobe is called the *optic*, and gives off an optic nerve to the eye. The lower or *antennary* lobes give off nerves to the antennæ; from their lower portion, close to the connectives, a nerve is given on each side to the labrum. From this, with other evidence, we conclude that the brain represents three paired ganglia from three somites, optic, antennary and the lost premandibular somite which was evident in the embryo.

The *para-œsophageal connectives* are two thick strands of nerve tissue which pass, one on each side of the œsophagus, from the brain to the sub-œsophageal ganglia and so complete the circumœsophageal nerve ring. The *sub-œsophageal ganglia*, as that name implies, lie between the œsophagus and the sub-mentum. They are large and give nerves to the three post-oral metameres, the mandibles and both pairs of maxillæ, so they represent the coalesced ganglia of three somites. Posteriorly they give off connectives to the thoracic ganglia.

After dissecting the reproductive organs and the alimentary canal, the latter should be drawn aside and the remaining fat-body and the muscles of the thorax removed to expose the *ventral nerve chain* which lies close above the sterna in the mid line. It is accompanied by a pair of tracheæ, one on each side, which the student must not mistake for the nerve chain itself, which is not of so silvery white a color.

The connectives lie close together touching one another. In the male the abdominal connectives are not straight, but a little wavy in their course to allow of stretching of the abdomen. There is a pair of ganglia in each thoracic segment. In the abdomen we find six pairs, recognised as dull white spots on the more translucent connective cord. The last pair lies above the seventh sternum and supplies all the somites posterior to it.

There is also a *visceral* system of nerves. From the front of each para-œsophageal connective a nerve is given off which, after giving a branch to the labrum, runs forwards and inwards to meet its fellow of the opposite side in the middle line and form a *frontal ganglion* on the anterior wall of the œsophagus. From the frontal ganglion a *recurrent nerve* passes back through the nerve ring along the dorsal wall of the œsophagus and crop for about 8 mm. beyond the ring, where it forms another ganglion from which two branches are given off to run backwards on the gut. Immediately beyond the nerve ring two pairs of ganglia are seen in connection with the recurrent nerve; to them from in front comes a nerve on each side from the posterior surface of the brain.

RESPIRATORY ORGANS.

We have seen the stigmata, openings into the tracheæ which in the course of our dissections we have found to ramify throughout all the organs and tissues of the body. In many animals such as the Vertebrates we have special organs, lungs or gills, for the taking in of oxygen and the giving out of carbonic acid from the blood, hence these animals require

an elaborate system of blood vessels to carry the oxygen to distant parts of the body. In Insects as the oxygen is carried in the tracheæ directly to all the tissues, a complicated circulatory system would be superfluous. The various branches of the tracheæ repeatedly anastomose with one another, so that if one or more stigmata should become blocked the tracheæ supplied by them can still carry on their functions.

The tracheæ originate as ingrowths of the epiblast, so its epithelial cells secrete a chitinous lining for the tubes. This chitin forms a spiral thickening which is elastic and keeps the tube from collapsing.

Examine a trachea in water with the microscope and note the spiral thickening; note the silvery white color of the trachea by reflected light when the diaphragm of the microscope is closed.

REPRODUCTION.

After copulation the semen is stored in the spermatheca. The eggs are about 5 mm. long and each has a tough brownish shell ornamented with small hexagonal tubercles, and perforated with small holes or micropyles. As the eggs are passed out of the vagina into the genital pouch they are met by the spermatozoa from the spermatheca which enter the micropyles and fertilise the eggs. The eggs are laid sixteen at a time and are held together by the gonapophyses while the secretion of the cement glands forms a capsule round them. The capsule resembles a miniature cigar-case and is at first pale, but with exposure to the air soon turns a dark mahogany color. The female usually carries the egg

case protruding from the genital pouch for about a week before depositing it.

It is said that the eggs do not hatch out for about a year in Northern Europe, but in India we have seen the young leave the egg within a month of the capsule being laid. The young " nymphs " are at first white excepting their large black eyes, but they very soon become brown. They resemble the adult in external form except that in neither sex have they any wings. They moult about seven times in their life-time. European observers say the Oriental Cockroach takes about four years to reach its adult condition. Rapidity of development in most insects depends largely on temperature, being retarded by cold, accelerated by warmth.

MOSQUITOES.

Every year in India these tiny insects kill a dozen men for the one man killed by snakes, tigers, leopards, lightning, earthquakes and war, all taken together. The diseases they produce cause nearly as many days' illness and incapacity for work as all other diseases combined.

They are the carriers of the germs of malaria and elephantiasis, as well as of yellow fever, a disease as yet fortunately not existent in India.

None of these diseases can be contracted except through the bites of mosquitoes. It is therefore essential not only for the medical, but also for the lay student to study the mosquito and its breeding places, as it is impossible to destroy these insects if the general public do not co-operate with the sanitary authorities.

We have seen that the young cockroach is hatched out of the egg in form closely resembling its parent. In contrast, the life history of the mosquito, of all other flies, of butterflies and of many other insects is divided into four clearly defined stages :—

(1) The Egg.

(2) The Larva (maggot, caterpillar, or grub), a stage of active feeding and growth.

(3) The Pupa (or chrysalis), a stage of relative rest as regards its environment, but of very active metabolism, disintegration and rebuilding of many organs. The pupa can take no food.

(4) The Imago or adult winged insect.

The eggs are in most cases laid by the mosquito on the surface of water, but in rare cases they are, in anticipation of rain, laid on mud or even on dry earth.

The larval stage of the mosquito is always passed in water where the larva feeds on minute particles of animal and vegetable matter which it sweeps into its mouth with its large feeding brushes. Some are very voracious and if other food is scarce, do not hesitate to turn cannibal and eat their fellow larvæ. They are unable to use the oxygen dissolved in the water for the purpose of respiration, but must needs every few seconds wriggle up to the surface to breathe the atmospheric air.

In the day time adult mosquitoes should be searched for in dark corners, on curtains, in clothes presses and on sheltered bookshelves. They may be caught by quietly placing the mouth of a test tube over them. A card or piece of stiff paper may then be slipped between the mouth of the tube and the object on which the insect rests. When the insect flies to the depth of the tube the latter should be closed with a cork or a plug of cotton. If you have not a test tube at hand a wine glass can be used.

Anophelines may be found in dark huts, especially on the rafters and on straws hanging from the thatch. They are particularly common in stables, cattle-sheds and in coach-houses where they are fond of resting on the cloth lining of carriage hoods. Leather-lined hats and caps offer a special attraction to both anophelines and culicines. Adult mosquitoes can most readily be obtained by allowing larvæ or pupæ to develop.

The larvæ of Culex can be found in most collections of fresh or even brackish water, especially if they contain some decomposing leaves. Old neglected pots, *chattis*, tubs and disused tins are prolific breeding places.

The larvæ of Stegomyia are often found in tubs and barrels and in the hollows of bamboo stumps in which rain-water has collected. The drinking water and the bilge water of most country boats swarm with them. Stegomyia keeps on the wing and bites day and night. Most other mosquitoes are nocturnal, resting during the day.

Anopheline larvæ are to be found in shallow pools at the side of slow running nullahs, small collections of clean water in rocks and in the beds of rivers during the dry season.

In Bombay City they are common in the rills caused by leakage from the reservoirs on Malabar Hill and at Mazagon. One species, *A. stephensi*, is to be found in clean water in tins, in little-used jugs and *chattis* and in cisterns. At times they can be found in almost every well and pool in the Fort. The commonest species, *A. rossii*, is found in roadside puddles all over the city. Fortunately it is not a carrier of the malaria parasite. Anopheline larvæ have a habit of resting with their "tails" close to the edge of the pool or vessel, their heads pointing to the centre.

Larvæ are best caught by quietly dipping a saucer or a spoon or ladle, preferably white in colour, a little below the surface at some distance from the edge of the pool. This should be done gently so as not to disturb the larvæ or stir up the mud. Quietly sweep the ladle under the surface up to the edge of the pool. Any larvæ will show up clearly against the white ladle which should then be smartly lifted

out of the water. The larvæ can then be transferred to a jar or wide-necked bottle. As the startled larvæ sink to the bottom, the excess water can be poured off and another catch of larvæ added. A piece of cork or wood should be allowed to float in the bottle for the winged insects to rest on when they hatch out. A piece of muslin tied over the mouth of the vessel will prevent the escape of the insects. Mosquito eggs look like particles of soot floating on the surface.

The mosquito belongs to the Diptera, (Gr. *di*, two; *ptera*, wings) or order of two-winged insects which includes the flies, gnats and midges.

A typical insect like the Cockroach has two pairs of wings, but in the Diptera the posterior pair have degenerated into mere vestiges known as the *halteres* or balancers. The anterior pair, which alone are developed as flying organs, are usually transparent and membranous in character. In the adult, the mouth is adapted for sucking and often for piercing. In the course of development there is a complete metamorphosis. The larva is often destitute of legs and aquatic in habit.

The Culicidæ or Mosquitoes are distinguished from all other Diptera by—(*a*) their proboscis which is long and formed for piercing as well as sucking; (*b*) the arrangement of their wing-veins; (*c*) by the fact that these veins are covered with scales, the interspaces remaining naked and membranous; and (*d*) the presence of a thick fringe of scales on the hind margin of the wings.

The classification of mosquitoes is in such a chaotic condition and subject to so frequent revolutions that we will

Fig. 41.
ANOPHELES STEPHENSI.

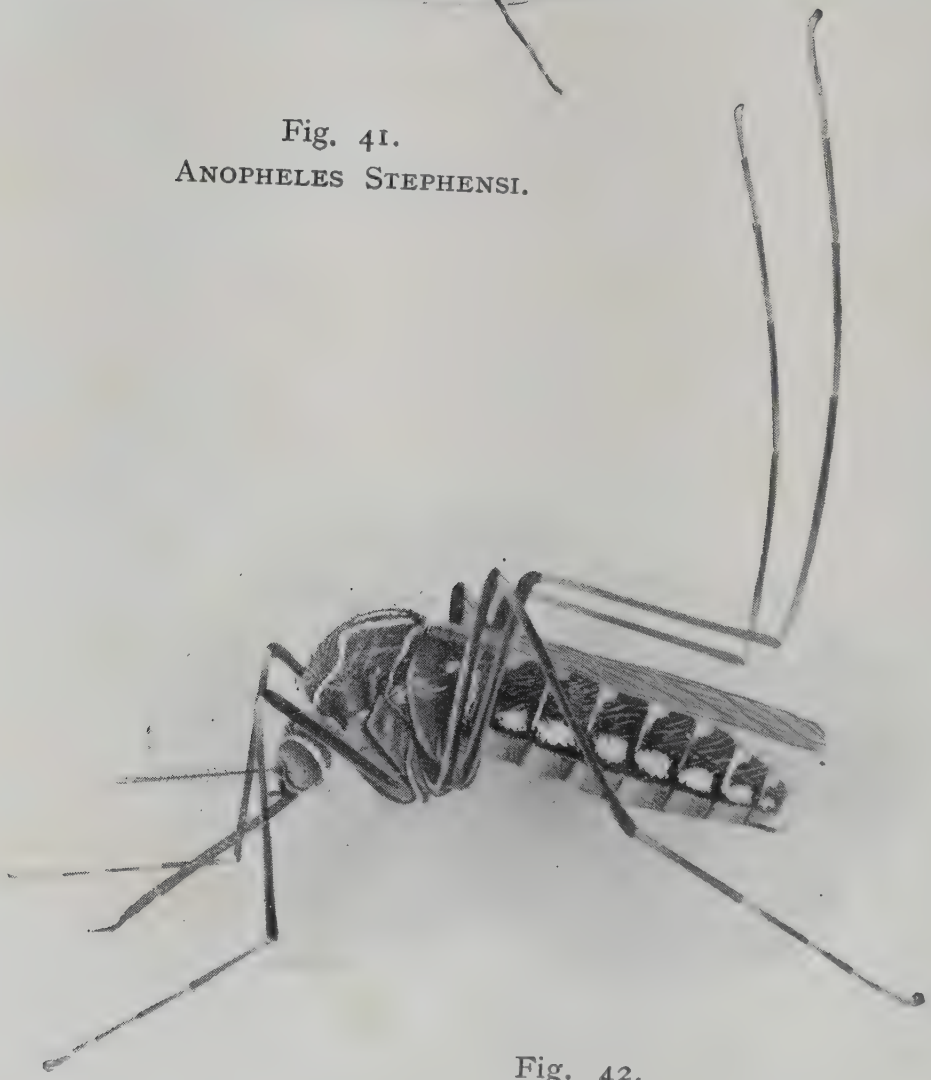

Fig. 42.
STEGOMYIA CALOPUS, THE CARRIER OF THE YELLOW FEVER GERM.

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not dictate any to the student but merely point out the characters of those genera convicted of conveying the germs of diseases.

ANOPHELINI.

(Gr. *anopheles*, hurtful, noxious.)*

These come first in importance as most species are capable of transmitting the parasite of malaria to man. They are dull coloured insects, usually with spotted wings. The maxillary palps in both sexes are about as long as the proboscis. The hind margin of the scutellum forms an undivided curve. (See Fig. 48.) The insect usually stands head

Fig. 39.

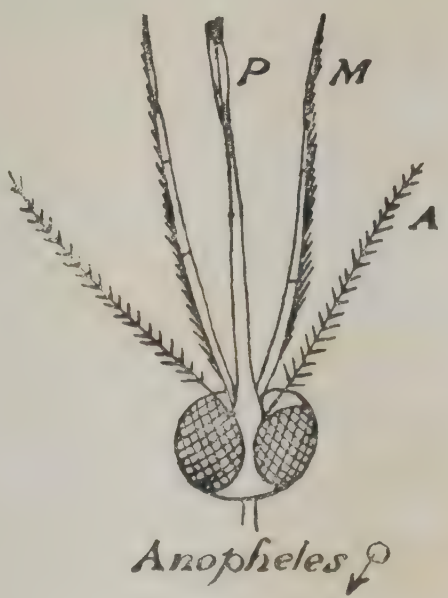

Fig. 40.

A. = A. Antenna. *P.* = Proboscis. *M.* Maxillary Palp.

* This name was given by Meigen a hundred years ago, long before the cause of malaria was discovered. He little knew how appropriate was the name.

downward, its body forming an acute angle with the surface on which it rests. The proboscis and the body are in approximately the same line. The larva has no respiratory siphon, and generally rests in a horizontal position at the surface of the water owing to the fact that the two respiratory openings are almost on a level with the dorsum. There are palmate scales on at least some segments of the abdomen (See Fig. 56).

The eggs of all the common species have special floats and frills and do not unite into egg-rafts.

CULICINA.

The maxillary palps, though long in the male, are very short in the female. When resting, the head and posterior end are about the same distance from the surface on which the insect rests. The head and proboscis are not in the same plane as the abdomen, but form an angle with it, thus giving a hump-backed appearance to the animal. (See Fig. 42.)

The hind margin of the scutellum is three lobed.

In the larva the tracheæ end in a long syphon through which respiration is carried on. The larva hangs head downwards in the water, the syphon opening at the surface.

There are no palmate scales. The eggs are provided with neither frills nor floats but are usually united into rafts. Those of Stegomyia have frills but no floats and do not form rafts.

Like other insects the Mosquito's body is composed of three easily recognised regions—head, thorax, and abdomen.

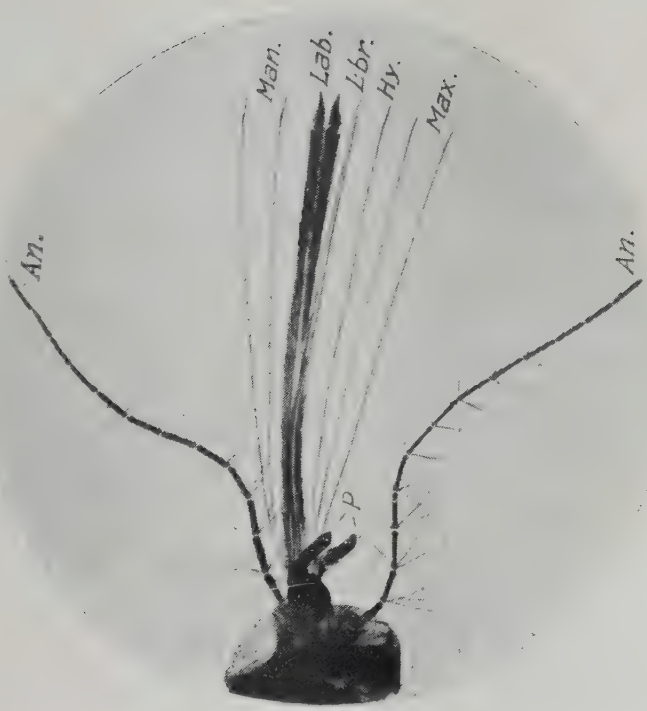

Fig. 45.—*Head of a female Culex.*

Fig. 46.—*Head of a female Anopheles.*

An.—Antennæ.
C.—Clypeus.
Epi.—Epicranium.
Hy.—Hypopharynx.
Lab.—Labium.
Lbr.—Labrum.
Man.—Mandibles.
Max.—Maxillæ.
P.—Palps of maxillæ.

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THE HEAD.

The compound eyes are very large and round, covering the greater part of the head. There are no ocelli.

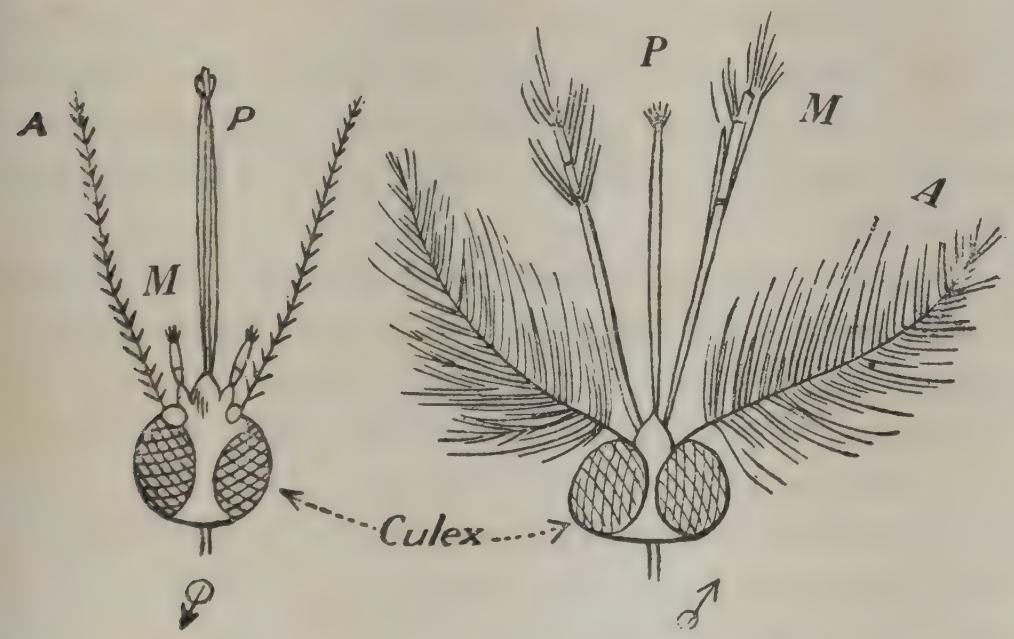

Fig. 43. Fig. 44.

A.=Antenna. *P.*=Proboscis. *M.*=Maxillary Palps.

The CLYPEUS projects well forward instead of being in the same plane with the EPICRANIUM as in the Cockroach. Note that it is covered with hairs in Culex, scales in Stegomyia.

The LABRUM is modified into a long pointed dagger, grooved on its ventral surface like a surgeon's director and presents little resemblance to the overhanging lip of the Cockroach.

The paired APPENDAGES OF THE HEAD are—

(1) The ANTENNÆ.
(2) The MANDIBLES.

(3) The First Maxillæ.

(4) The Second Maxillæ fused throughout the greater part of their length and usually called the **Labium.**

The antennæ are clothed with silky hairs and generally consist of fourteen segments,—fewer than in the Cockroach. The antennæ of the male are much more feathery than those of the female and offer a ready means of distinguishing the sexes.

On examining the head in its normal condition, the maxillary palps will be seen, but all the other mouth parts are concealed in the groove of the labium which forms a sheath to enclose the piercing apparatus. The whole is known as the proboscis.

To see the parts of the proboscis, brush the head carefully with a camel-hair pencil to remove the scales. Cut off the antennæ and maxillary palps. Then cut off the clypeus with the proboscis. Mount in water, press the coverglass down firmly with the point of a pencil, watching the effect under a low power. If successful, the various parts will be separated from one another. If unsuccessful, try again, separating the parts with a pair of needles. Another head should be boiled in *Liquor Potassæ* and stained with fuchsin.

The proboscis consists of—

(*a*) The Labrum or upper lip.

(*b*) The Hypopharynx or tongue.

(*c*) The Mandibles.

(*d*) The first Maxillae, commonly called the maxillæ.

The above are all enclosed in the groove of—

(*e*) The Labium or united second Maxillæ.

(*a*) The LABRUM has already been likened to a surgeon's director. The groove is, however, deeper, so that a cross section would occupy more than three-fourths of a circle, and resemble the Greek letter Ω or the cover of a motor tyre in section. The tip is bevelled off to a sharp point.

(*b*) The HYPOPHARYNX or tongue.

In the Cockroach the salivary duct opens at the base of the tongue. In the Mosquito the duct is continued to the tip of the hypopharynx as a very minute tube. The tubular portion bears two lateral flanges, so that the whole hypopharynx forms a long flat strip which can be applied to the under surface of the labrum, converting its groove into a tube up which the blood or other food of the insect is sucked.

(*c*) The MANDIBLES are a pair of very fine rods or stylets of chitin. In some Mosquitoes the tips are toothed like a saw.

(*d*) The FIRST MAXILLÆ have a pair of rod-like laciniæ resembling the mandibles. Each has a palp attached to its base. The laciniæ are generally absent in the male. Under the microscope the hypopharynx, mandibles and laciniæ look like five golden wires.

(*e*) The LABIUM or lower lip is formed of the two second maxillæ united to form a grooved sheath or gutter, in which the piercing organs rest.

The labium is the part of the proboscis usually seen when that organ is undisturbed by pressure or dissection. Its under surface is rough and scaly. Two small leaf-like LABELLA are attached by a joint to the distal end of the labial spout. (Fig. 45, Lab.).

The labium does not penetrate in the act of biting, but serves as a guide to the rest of the proboscis, becoming doubled up on itself into a loop, while the stylets, labrum and hypopharynx pierce the skin.

The MAXILLARY PALPS are most commonly four-jointed. In the Culicine female there are only three joints.

As the hypopharynx often sticks closely to the labrum, and its lumen is not evident when looked at longitudinally, transverse sections of the proboscis should be made to properly understand its structure and relations.

Dehydrate the Mosquito in absolute alcohol; embed in celloidin. Cut transverse sections. Note the large labium concave on its upper surface. Observe two large tracheæ

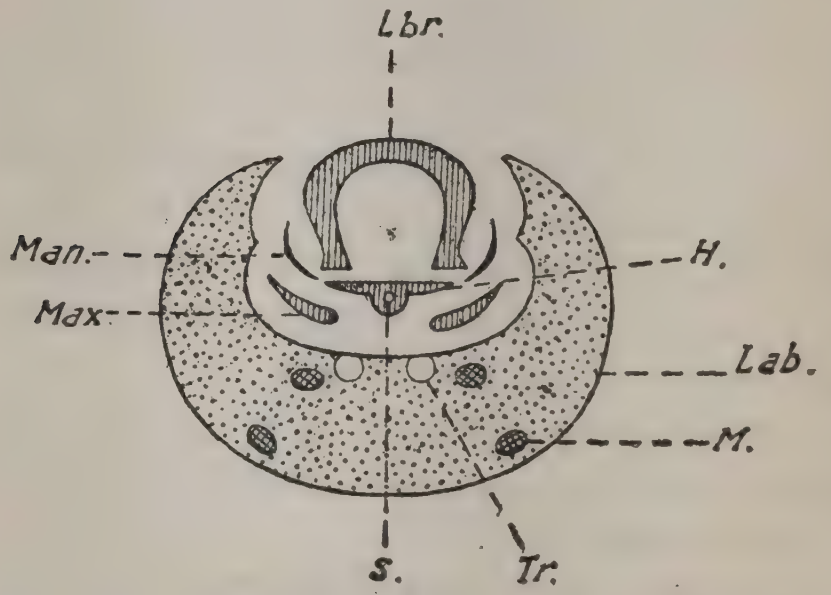

Fig. 47.—*Transverse section of Proboscis.*

H.—Hypopharynx.
Lab.—Labium.
Lbr.—Labrum.
M.—Muscle.
Man.—Mandible.
Max.—Maxilla.
S.—Salivary duct.
Tr.—Trachea.

near the middle line. In the groove note the other parts of the proboscis, *viz.*—

(1) The labrum, above, like an inverted U.
(2) The hypopharynx below the labrum, closing its groove, looks like a transverse section of a blade of grass, its mid-rib being pierced by the salivary duct.
(3) The mandibles, crescentic in section.
(4) The first maxillæ, larger than the mandibles.

THE THORAX.

The three segments—pro, meso, and meta-thorax are easily recognised from the ventral and lateral aspects. Dor-

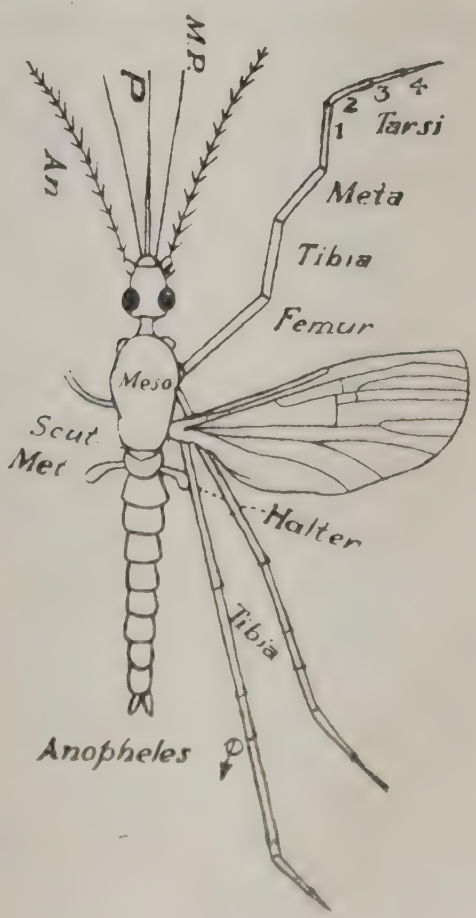

Figure 48.—Female Anopheles—
An. = Antenna.
M. P. = Maxillary palp.
P. = Proboscis.
Meso. = Mesonotum.
Scut. = Scutellum.
Met. = Metathorax.

sally, however, only two thoracic terga are visible. Of these the anterior is large, covering much the greater portion of the thorax. It is the MESONOTUM. Its posterior margin presents a lip known as the SCUTELLUM, which is of importance to entomologists in classification, as the hairs or scales are of different kinds in different species. Its hind margin is three lobed in Culicini, undivided in Anophelini.

Behind the scutellum is seen the small METANOTUM to which the halteres are attached.

The PRONOTUM is scarcely recognisable except its outer ends known as the PATAGIA which look like small epaulettes.

The APPENDAGES of the Thorax are THREE PAIRS OF LEGS attached ventrally, one pair to each segment, the WINGS and the HALTERES.

Morphologically the legs resemble those of the Cockroach, and consist of the following segments :—

(*a*) A short stout COXA.
(*b*) A very short TROCHANTER.
(*c*) A long straight FEMUR.
(*d*) A long straight TIBIA.
(*e*) A TARSUS of five joints, the last of which is variously clawed or hooked, and differs in the male and female.

Remove the three legs of one side, place them in order on a slide, cover with a drop of balsam, put on a cover-glass, and note the above points.

The WINGS spring from the side of the mesonotum. Note that it is the first pair of wings with which the Mosquito flies, while in the Beetle and Cockroach they have no flying function, but are hard wing-cases for the protection

of the functional wings,—the second pair. Remove the wings as close to the thorax as you can and place, dorsal surface upwards, on a slide. Put two minute dots of thick balsam on the slide just where the edges of the cover-glass will overlap them. See that the wings are not touched by the balsam, the object of which is to hold on the cover-glass. Press down the cover-glass ; ring with hard paraffin.

Note the " veins " or " nervures " of the wing, covered with scales, while the intervening spaces or " cells " are naked and membranous.

Observe the spots on the wings of Anophelines.

The arrangement of the veins on the wings is characteristic for the Mosquitoes, and to each vein a name is given as indicated in the diagram Fig. 49.

The border is called the *costa*, anteriorly it is straight and strong, posteriorly thin, curved and fringed with scales.

Note that the second, fourth and fifth longitudinal veins are forked at their distal ends.

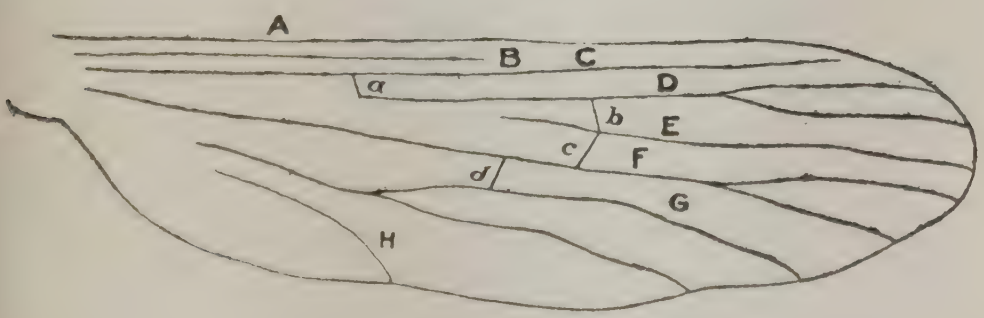

Fig. 49.

Venation of Mosquito's Wing. A=Costa. B=Sub-costal, C=First, D=Second, E=Third, F=Fourth, G=Fifth, H=Sixth longitudinal, *a*=First, *b*=Second, *c*=Third, *d*=Fourth cross-vein

The HALTERES or balancers, will be seen attached to the metanotum on each side as small club-shaped processes, the vestiges of the second pair of wings usually found in the Insecta.

THE ABDOMEN.

The abdomen consists of eight segments, each covered dorsally by a tergum, ventrally by a sternum.

These chitinous plates are laterally united by a thin continuous pleural membrane, in which may be seen the openings of the abdominal spiracles, a pair for each segment.

The anus with the genital aperture below it opens posteriorly on the last segment between the gonapophyses or appendages used in facilitating copulation or the laying of eggs, and which therefore differ in the sexes.

THE ALIMENTARY CANAL.

To dissect the alimentary canal kill the Mosquito with benzol, petrol, chloroform, or tobacco smoke. Fix the thorax by piercing it with a needle, pick off the wings and legs. Brush well but gently with a camel-hair pencil to remove the scales. Place in a drop of saline solution on a glass slide over a board or card half of which is painted white, half black.

Gently flatten out the hinder portion of the abdomen about the seventh segment. With a sharp-edged needle or cataract knife make two lateral nicks through the abdominal wall. This will so weaken the wall that you can break it completely by laying the needle flat on the segments you have partly detached, and steadily but gently pulling them apart from the anterior segments.

Shift the slide over to the black part of the board. You will now see against the dark background, the white intestine and Malpighian tubes.

Slowly and patiently continue your traction, till all of the white opaque mid-gut appears, and you see the hinder part of the œsophagus, recognisable by its thinner and more translucent character.

Now move the needle up to the exposed part of the œsophagus and with its shaft gently pull out the remainder of the œsophagus.

While traction is kept up, a little teasing or cutting of the exoskeleton under the microscope will help to remove a more complete œsophagus.

The alimentary canal consists of the following parts :—

The MOUTH	STOMODÆUM OR FORE-GUT.
The PHARYNX with bulb	
The ŒSOPHAGUS and diverticula ..	
The MID-GUT, commonly called the "stomach"	MESENTERON.
The HIND-GUT	PROCTODÆUM.

The mouth and pharynx are lined with chitin, not so the œsophagus or the hind-gut, though they also are derived from the epiblast.

In the head the anterior portion of the pharynx is narrow and surrounded by the "œsophageal" nerve ring. Behind this it dilates into a suctorial bulb acted on by powerful muscles. It again becomes narrow and makes a sharp bend where the chitinous layer ceases and the œsophagus begins.

The ŒSOPHAGUS is very thin walled. From it three DIVERTICULA arise, recognisable to the naked eye as white dots, but under the microscope looking like a number of air bubbles entangled in a thin membrane. In the newly-

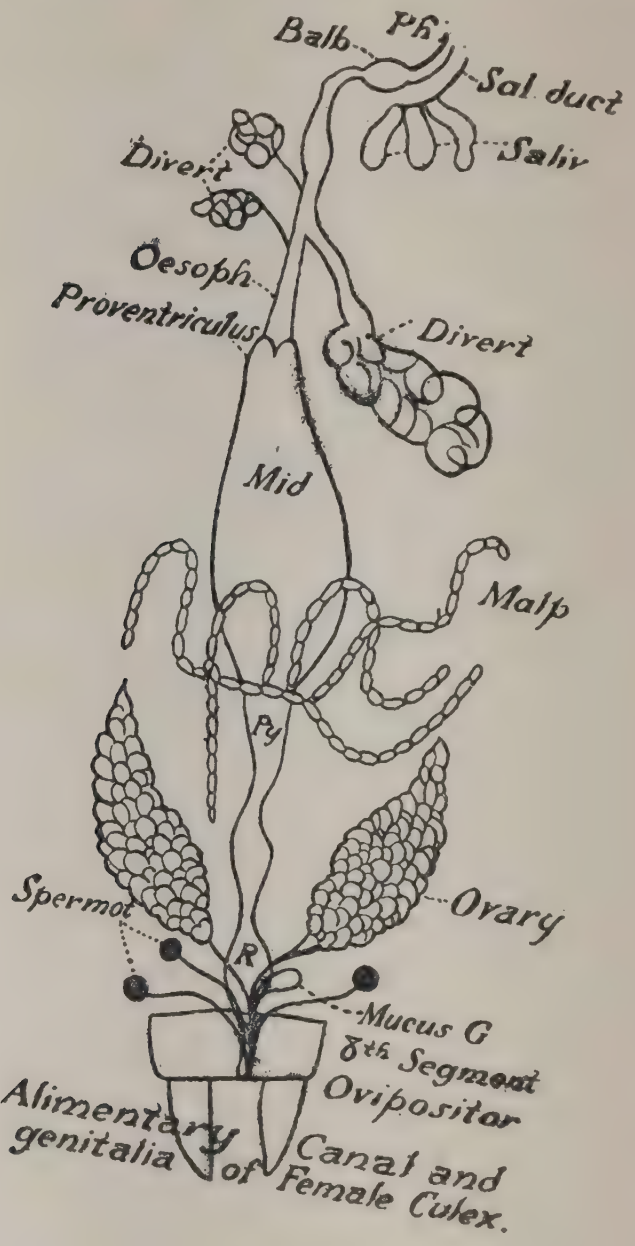

Fig. 50.

fledged Mosquito they are small, but they rapidly increase in size *pari passu* with the insects' powers of flight. One extends backwards into the abdomen. As they arise from the fore-gut they are obviously not homologous with the hepatic cæca of the larva or of the Cockroach which arise from the mid-gut. They usually contain many bacteria.

There is no gizzard which would be of no use to an animal like the Mosquito living on fluid food, such as blood and the juices of plants. The mid-gut extends backwards to the origin of the MALPIGHIAN TUBES. Its anterior portion is narrow, the posterior portion dilated in proportion to the amount of food it contains ; when full it distends almost the whole of the abdomen.

If the anopheline has sucked the blood of a man suffering from malaria and become infected, at the end of a week's time on the outer surface of the mid-gut with the aid of a good lens, there may be seen minute cysts which contain thousands of malaria parasites. These cysts soon rupture into the fat body, discharging the parasites which make their way to the salivary glands. When the mosquito next bites a man she injects the parasites along with her saliva into the puncture.

It will be noted, that the whole of the fore-gut is usually found quite empty of blood or other food even immediately after feeding.

The MALPIGHIAN tubes open into the proximal end of the hind-gut. Three pairs of PAPILLÆ, each supplied by a large tracheal vessel, project into the lumen of the rectum or terminal portion of the hind-gut. The anus opens on the posterior aspect of the last abdominal segment.

THE DIGESTIVE GLANDS.

The salivary glands lie one on each side of the œsophagus. Each consists of three lobules with their ducts. The three ducts soon unite into right and left ducts which join below the subœsophageal ganglion to form a common duct which, as already seen, traverses the whole length of the hypopharynx.

You may note that all these lobules are secretory in function, but that usually the lumen of the middle lobule is larger and the cells lining it clearer and less granular than those of the upper and lower lobes, showing an approach to the cystic condition found in the Cockroach.

There are no hepatic cæca or diverticula in the imago.

To detect malaria parasites in the salivary glands the medical student should be able to dissect the glands out cleanly and rapidly. Take a female anopheles, pick off the wings and legs ; brush off as many scales as possible ; lay the insect on its back ; steady the thorax with one needle and with another steadily and gently pull off the head. Be careful not to break up the eyes as much pigment would escape and make the preparation very messy. The glands will thus be drawn out fairly clear of fat-body, from which they can be distinguished by their shape and by the fact that they are whiter, more transparent and more glistening. It is, of course, useless to look for the parasites in the male as he is a pure vegetarian, feeding solely on the juices of plants and never sucks blood.

To dissect the salivary glands of Culex or Stegomyia it is best to place the insect first on its side, slice off the " hump "

of the thorax with a cataract knife ; then turn the insect on its back and proceed as with Anopheles.

Any doubt as to whether you have got the glands or a piece of fat-body can be set at rest by noting the three lobular ducts uniting to form the main duct. To find malaria parasites, simply squash the glands between a cover-glass and a slide, make a smear, dry, fix with alcohol and stain with Romanowski.

THE EXCRETORY SYSTEM.

The MALPIGHIAN TUBES are only five in number opening into the commencement of the hind-gut. They are lined with large opaque granular cells with large nuclei, the lumen presenting a zig-zag appearance.

THE CIRCULATORY SYSTEM.

The circulatory system resembles that of the cockroach and other insects. A longitudinal dorsal vessel opens in front into the hæmocele in which we find the fat-body surrounding the viscera. In insects generally we find some large pear-shaped *pericardial cells* around the dorsal vessel and on the pericardium. Their function is not known, but they contain many nuclei and often inclusions, possibly

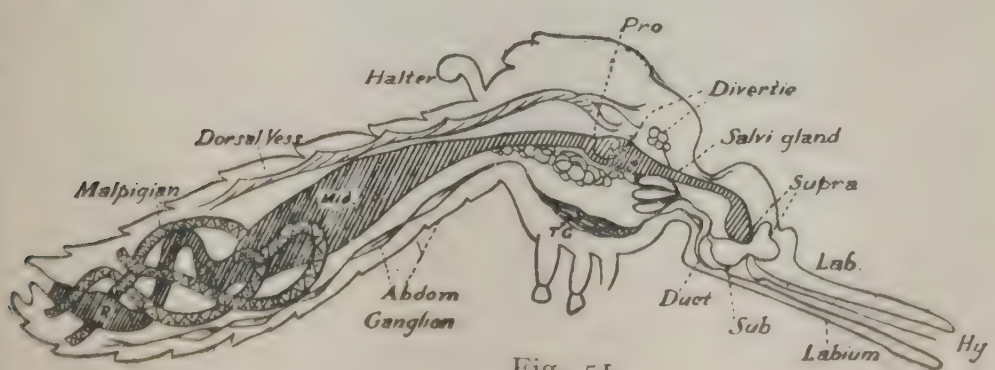

Fig. 51.

as a result of phagocytosis. A piece of the dorsal vessel should be removed and these cells observed as they are likely to be mistaken for parasites by the inexperienced.

THE NERVOUS SYSTEM.

The respiratory and nervous systems are arranged on the plan usual among insects.

The description of the nervous system in the Cockroach will apply to the mosquito except that the three pairs of thoracic ganglia unite to form one large mass.

THE GENITAL ORGANS.

To dissect these cut partly through the anterior portion of the last segment, instead of the sixth or seventh, as you did to expose the alimentary canal, and proceed as in that dissection, gently pulling out the genital organs and as much of the alimentary canal as you can.

In the male the TESTES are a pair of elongated somewhat spindle-shaped whitish or yellowish bodies, their anterior portions or tips appearing less granular under the microscope than the opaque posterior part. Posteriorly they are attached to the VASA DEFERENTIA, a duct for each testis. Just before their termi-

Male Genital Organs.

Fig. 52.
E.=Ejaculatory duct.
P.—Penis.
I.G.=Internal gonapophysis
Ex. Gon.=External " "

nation each communicates by a short duct with a SEMINAL VESICLE, a small sac for storing the semen.

The vasa unite to form a short muscular EJACULATORY DUCT which terminates in a short fleshy PENIS projecting from the last abdominal segment below the anus.

On each side of the penis are two GONAPOPHYSES, backward projections of the last segment.

The outer pair are the two stout processes which to the naked eye give the bifid appearance to the posterior end of the insect. They bear on their inner or opposed surfaces a pair of stout, sharp chitinous hooks used as claspers for holding the female during copulation. The median pair of gonapophyses are much smaller.

In the female we find a pair of spindle-shaped OVARIES. In the newly-fledged insect they are very small and contained in a single segment of the abdomen, but they rapidly grow so that in the living impregnated female they are easily seen with the naked eye, extending into several segments, as large, white patches, contrasting with the gut, dark-red when full of blood.

Each is made up of a cluster of spindle-shaped follicular tubes, commencing as fine filaments and opening by their bases into the OVIDUCT.

In a mature female eggs in all stages can be seen in each tubule, the youngest being at the filamentous end. The oviducts pass backwards from their respective ovaries to unite in a COMMON OVIDUCT, which opens below the rectum. Just before it opens, the common duct is joined by the ducts of three SPERMATHECÆ, small dark vesicles in which the spermatozoa are stored after copulation. It is also joined by

the duct of the CEMENT GLAND, the secretion of which forms an outer coating for the eggs and cements them together to form the egg-rafts. Anophelines have only one spermatheca; *Mansonia* a Culicine genus, has only two.

Projecting from the posterior part of the last segment are the gonapophyses, or ovipositors, a pair of somewhat trowel-shaped processes, which are used in launching the egg-boats.

DEVELOPMENT.

Copulation takes place while the insects are on the wing. The semen is then stored in the spermathecæ of the female, so that a single act of copulation may suffice to fertilise more than one batch of eggs.

In the smaller ovarian follicles the nucleus of the egg can be clearly seen, but it soon becomes obscured by the accumulation of yolk.

The female is able to stand on the surface of the water with her front four legs, owing to the tension of the surface film. The female culex crosses the two hind tarsi and with the help of the ovipositors holds the eggs vertical, with the thicker end downwards, in close apposition. The eggs are covered with the sticky secretion of the cement glands which quickly sets on exposure to the air. In this way two or three hundred are united to form a boat-shaped raft, which is lowered on to the surface of the water as soon as the cement has set.

The eggs of the Culicines with the exception of *Stegomyia*, are much elongated, and broader at the lower pole to which is attached a clear round process which is easily

broken off, sometimes leaving a small spine exposed. They have no air cavities in the form of either frills or floats.

Stegomyia, the Tiger Mosquito, does not build rafts. The eggs are oval and surrounded by a frill of small air-spaces formed by a reticulation of the outer cover, which serves to keep them afloat. They are sometimes laid on mud or even on dry earth where they can survive for weeks till rain falls and a pool is created.

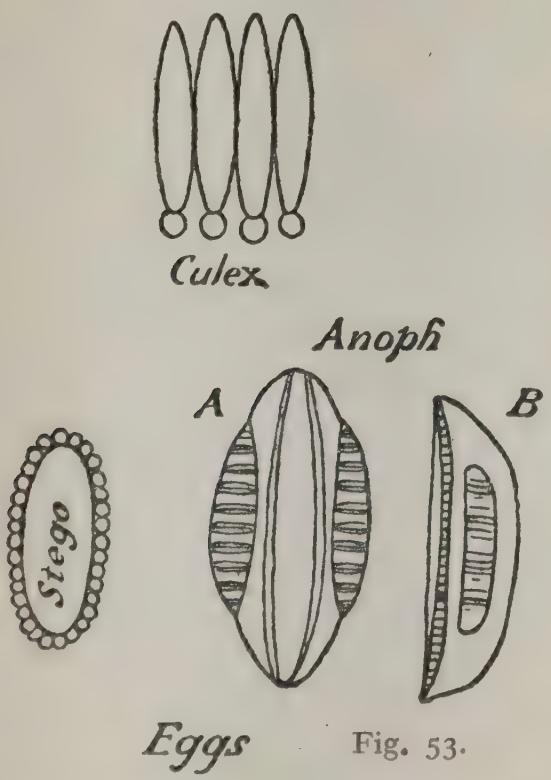

Fig. 53.

Stego = Egg of Stegomyia. *A* = Dorsal view of Anopheles' egg. *Culex* = Four eggs of Culex. *B* = Lateral view of Anopheles' egg.

The eggs of Anophelines are not united into rafts. They are very beautiful objects of a definite boat-shape. The flat or concave upper surface or deck, is surrounded by a gunwale or frill, like that of *Stegomyia*, but has in addition in

all species except *A. turkhudi,* a pair of lateral floats which ensure its buoyancy.

THE LARVA.

Examine a small larva in a drop of water under a cover glass to restrain its movements.

The body will be seen to be made up of head, thorax and abdomen, the whole being so transparent as to allow much of the internal anatomy to be made out without dissection.

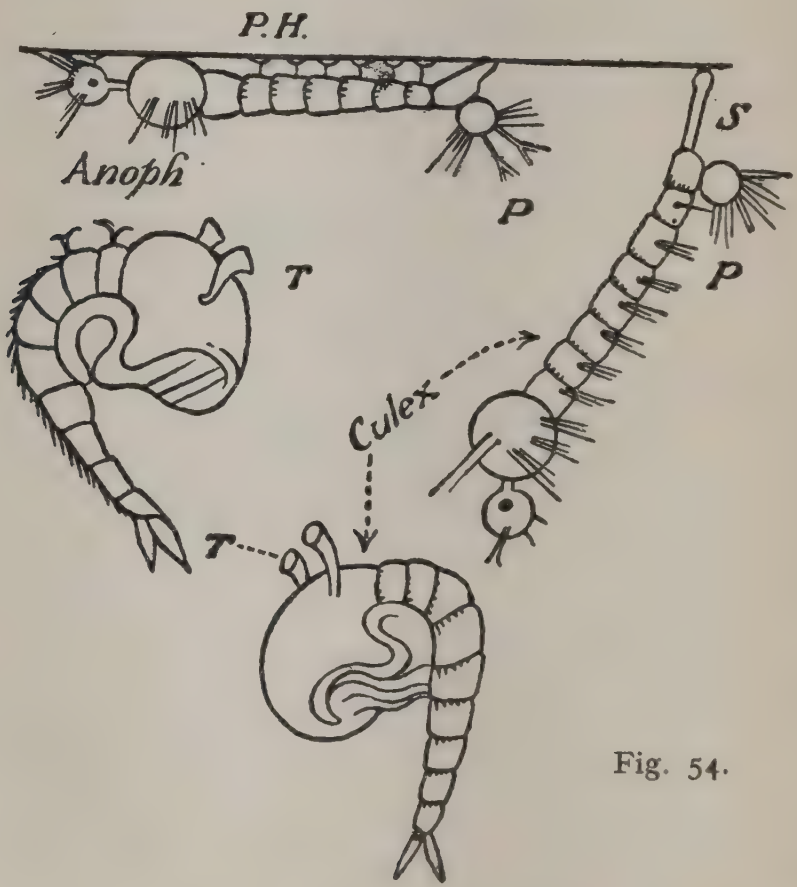

Fig. 54.

P. H.=The palmate scales. *S*=Syphon. *P.*=Anal papillæ. *T* =Trumpet of pupa.

THE HEAD.

The head is large and rounded. Its dorsal surface is covered by the epicranium, which is marked laterally by a pair of compound eyes and a pair of simple eyes or ocelli. In front arise the antennæ, much simpler structures than in the imago.

From the under-surface of the clypeus, arise the feeding brushes. These usually bear a striking resemblance to a pair of shaving brushes and may be seen rapidly moving in front of the mouth at frequent intervals. Their function is to sweep food material into the mouth, the serrations of the jaws acting as combs to remove entangled particles.

In addition to the brushes the clypeus bears a few hairs,

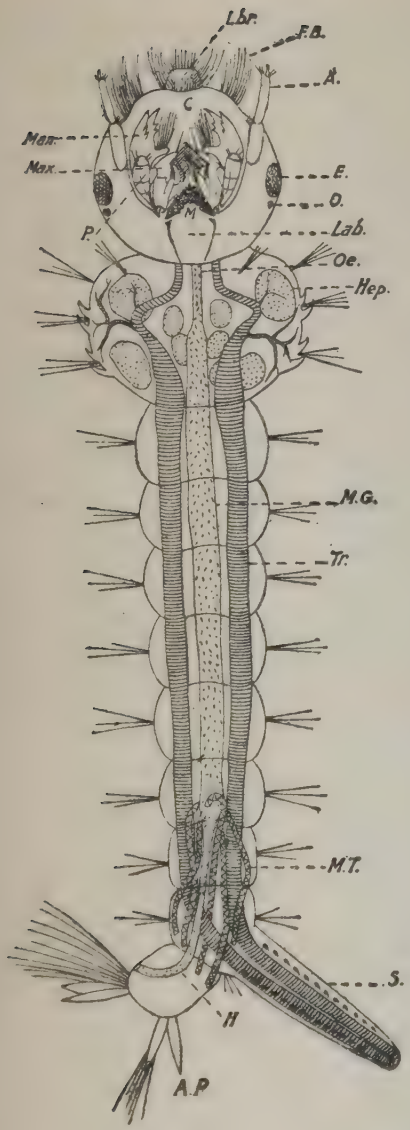

Fig. 55.—*Diagram of a Culex larva. The circulatory and nervous systems have not been drawn for the sake of clearness.*

A.—Antenna.
A. P.—Anal papillæ.
C.—Clypeus.
E.—Eye.
F. B.—Feeding brush.
H.—Hind-gut.
Hep.—Hepatic Cæca.
Lab.—Labium.
Lbr.—Labrum.
M.—Mental plate.
Man.—Mandible.
Max.—Maxilla.
M. G.—Mid-gut.
M. T.—Malpighian tube.
O.—Ocellus.
Oe.—Oesophagus.
P.—Maxillary palp.
S.—Syphon.
Tr.—Trachea.

the number and character of which are of much importance in classification.

The mandibles and maxillæ are strong and toothed on their opposable surfaces to adapt them for seizing and tearing solid food. They bear a greater resemblance to those of the Cockroach than to the stylets of the adult Mosquito.

Posteriorly the mouth is closed by the labium, the anterior part of which is known as the *mental plate*, a dark dentated plate of chitin of very characteristic shape. The labrum is attached to the clypeus and closes the mouth anteriorly.

THE THORAX.

The thorax is more or less globular in shape. It bears no wings or jointed appendages, and there are no separate terga or sterna for the three segments of which it is composed, but these three segments are indicated by three lateral pairs of unjointed tubercles, each bearing a tuft of bristles.

THE ABDOMEN.

The abdomen consists of nine segments, each bearing a lateral tuft of bristles as well as numerous hairs. The Anopheline Mosquitoes have a pair of PALMATE SCALES on the dorsum of some of the segments, and in some species even on the thorax. These scales are shaped like the leaf of the fan palm and are very characteristic objects, having slight variations in shape in different species. Their shape and distribution are useful guides in classification.

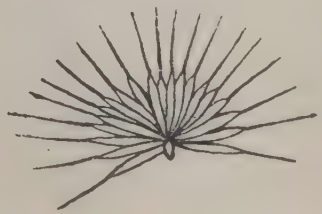

Fig. 56.—Palmate scale.

The tracheæ open on the dorsum of the eighth segment. In Anophelines the separate openings of the two great longitudinal tracheæ are on a level with the dorsal surface. In the Culicini, the eighth segment bears a dorsal projection, the *syphon* which gives the posterior extremity of the abdomen a forked appearance. The longitudinal tracheæ are continued up this syphon to open at its apex.

THE DIGESTIVE SYSTEM.

The buccal cavity opens into a short ŒSOPHAGUS followed by the MID-GUT, a straight tube that reaches from the middle of the thorax to the posterior part of the sixth abdominal segment where the five MALPIGHIAN TUBES mark the beginning of the HIND-GUT

At its anterior end in the thorax the mid-gut communicates with four pairs of digestive glands or HEPATIC CÆCA, which can be seen in the living larva as brownish lobules kept in constant motion by the communicated impulse of the dorsal vessel. In the dead larva they have discharged their brownish contents into the gut and are hard to recognise. There is no trace of them left in the imago.

The SALIVARY GLANDS lie close to the œsophagus, but are difficult to demonstrate except in sections.

THE CIRCULATORY SYSTEM.

The dorsal vessel can be seen in the living larva as a delicate pulsating tube lying dorsal to the gut and extending from the head to the posterior extremity.

It is expanded in each segment and is held in position by alary muscles. The pulsations are transmitted to the tracheæ and other organs.

THE RESPIRATORY SYSTEM.

The main longitudinal tracheæ are of very wide calibre. They open to the surface only by two stigmata already described, on the dorsum of the eighth segment in Anophelines; at the end of the syphon in Culicines.

THE NERVOUS SYSTEM.

This is not easily seen in the larval Mosquito. It differs from that of the adult, in that the brain is much smaller and in that there are three separate ganglia in the thorax, eight in the abdomen. The nervous system is readily seen without the trouble of dissection in the closely allied Chaoborus or "phantom larva" which is almost transparent.

THE EXOSKELETON.

The cuticle is repeatedly moulted or cast off during the growth of the larva. The inner lining of the tracheæ is also moulted at each of these periods of ECDYSIS.

The horizontal position of anopheline larvæ should be noted, also the rippled line on the surface of the water made by the palmate scales. Observe the great range of rotation of the head and how the larva does most of its feeding at the surface, turning the head ventral side upwards. Observe also they are much more jerky in their movements than Culicines.

THE PUPA.

The larva moults three times before it reaches full size. The lining of the tracheæ as well as the outer cuticle is cast

off at each of these ecdyses. When the larva is full grown the legs and some other organs of the imago can be recognised through the transparent cuticle. A fourth ecdysis then takes place when the larva becomes the pupa, resembling a comma in shape. The tail of the comma is the abdomen, the rounded mass is the head and thorax. The eyes can be seen through the cuticle as well as the antennæ, wings and legs folded up. In addition we find two respiratory trumpets which admit air below the cuticle and thence to the stigmata. The abdomen is curved and ends in a pair of thin oval tail-fins which enable the pupa to swim actively. The pupa stage lasts only a day or two, but in that time the imago is fully formed. The pupa then straightens out; the cuticle splits lengthwise along the dorsum of the cephalothorax, the head of the imago emerges through the slit and is slowly followed by the wings, legs and abdomen. The imago perches for a while on the empty cuticle of the pupa till its wings are dry and hard enough to fly.

Unlike chrysalids and the pupæ of most insects, that of the mosquito retains its power of locomotion and is very agile, spending most of its time at the surface of the water.

At the last ecdysis of the larva the tracheæ of the abdomen contract so that the centre of gravity is shifted, the tail end sinks allowing the trumpets to come to the surface. This is an essential act of adaptation as otherwise the imago would escape not into the air, but into the water and be drowned.

METAMORPHOSIS.

In all the Metazoa growth is not merely an increase in bulk, but is accompanied by development and consider-

able changes in structure from the fertilised egg-cell or zygote up to the adult condition.

In many animals, such as Man, Rabbit, Bird, Cockroach and Earthworm the more marked of these changes take place in the embryo or young animal before it is born from the womb or hatched from the egg. Throughout the rest of its existence the animal bears a considerable resemblance to its parent, as whose offspring it is readily recognised.

Other animals, such as the Frog, Crab, Spiny Lobster Butterfly and Mosquito, undergo striking changes after they have left the egg, and at first bear so little resemblance to the parent form that the inexperienced observer may well be excused for not recognising their relationship. Such young animals, when they leave the egg, are known as LARVÆ and the changes in form which they undergo are spoken of as METAMORPHOSES.

From the fish-like tadpole feeding on vegetable matter and respiring by gills, there is a gradual transition stage with mixed feeding and mixed respiration to the adult carnivorous Frog with ærial respiration.

In Crustaceans and Insects which possess a rigid armour of chitin, any great increase in bulk can only take place at the periods of ecdysis when the shell-like covering is thrown off. Something further is necessary in Insects like the Butterfly and Mosquito, where we have a worm-like LARVA with powerful chewing jaws formed for eating large quantities of bulky vegetable food, transformed into an imago with its mouth parts fitted for sucking liquid food only.

In the Insects the larva is chiefly engaged in assimilation and growth ; the imago or perfect Insect makes no increase in bulk and its principal function is reproduction.

Metamorphosis of structure is a necessary adaptation to change of habits and environment. To be able to fly it is essential that an animal should have powerful muscles, food easily absorbed, highly nutritious and containing little waste residue. The bulky wood and coal that suffice as fuel for the railway train or ocean steamer, must be replaced by pure hydrocarbons like petrol or benzol, in the flying machine. The coarse, bulky food of the caterpillar and mosquito larva would be a heavy and unprofitable handicap to a flying insect, hence we need not be surprised to find during the process of metamorphosis a change of structure in the biting parts of the mouth and in the digestive apparatus to adapt them for sucking in concentrated and readily assimilable foods, such as honey or blood, which leave little residue.

Having reached a maximum of bulk after several ecdyses the larva enters on a period of apparent rest known as the CHRYSALIS or PUPA stage. This rest is however only in relation to the animal's sourroundings, for internally very striking changes in structure are actively taking place. The amœboid corpuscles of the blood take on an extraordinary activity and well deserve their name of PHAGOCYTES, (Gr. eating cells) by devouring the greater part of the animal tissues which they reduce to a creamy mass, strongly reminding us of the yolk of the embryo, or the pus of an abscess. In this process of destruction or *histolysis*,* certain cells known as HISTOBLASTS, are spared, which are of embryonic

* Gr. *histos*, tissue, *lyo*, to dissolve or destroy.

character like those of the blastoderm, and proceed to rebuild the insect into its IMAGO condition, being fed by the yolklike mass.

Collections of these cells known as IMAGINAL DISCS or BUDS, are found in definite situations and from them are formed the wings, legs and the greater part of the new head-appendages which replace the old.

IDENTIFICATION OF ANOPHELINE MOSQUITOES.

All Anopheline Mosquitoes do not harbour the malaria parasite. It is therefore necessary for the medical man to distinguish the harmful from the harmless species. This work would require a volume to itself, therefore only a few remarks will be made to enable the student to identify the Anophelines to be found in Bombay City.

At present three species of Anopheles are common, two rare in this city. The five are :—

A. or *Nysso-myzomyia rossii* ..	..	brown.
A. or *Nyssorhynchus stephensi* ..	..	
A. or *Nyssorhynchus jamesi* ..	..	black.
A. or *Myzorhynchus barbirostris*	..	
A. or *Myzomyia culicifacies* ..	..	small brown.

A. rossii, the most common, is incapable of transmitting malaria, and is therefore comparatively harmless. It is found all over the City and is the only Anopheline that breeds in foul water. It is very like *A. stephensi* and often mistaken for it. The latter is the next most common Anopheline and is to be found in about half the wells in the Fort. It also breeds freely in cisterns, unused cans, jugs and other vessels as well as in slowly running nullahs and pools.

A. jamesi is next in order of frequence.

A. barbirostris is rare in the City.

To identify these insects note first their colour—

if they are brown they are :—	if black :—
A. rossii	*A. barbirostris*, large
A. stephensi	
or *A. culicifacies* ;	or *A. jamesi*, small.

A. culicifacies derives its name from the fact that it resembles a Culex in its attitude. It does not stand head downwards like other Anophelines. It further resembles a Culex in that the thorax is distinctly humped, the proboscis and the abdomen not being in the same line. The larvæ are found in running streams or in the borrow-pits beside the B. B. & C. I. Railway line near Mahim and Parel. It is rare, we have not seen any for years.

The larvæ can be distinguished from all other larvæ found in Bombay by the presence of palmate scales on the metathorax, as well as on the abdominal terga.

A. stephensi can be recognised by its brownish grey colour, by the fact its tibiæ and femora are speckled with white, and by the markings of the palps. The distal portion of the palps is marked by two broad white bands separated by a *narrow* dark band. (See Fig. 41.)

A. rossii on the other hand has no white dots on the legs except at the joints. The terminal white bands on the maxillary palps are separated by a *broad* dark band. The larvæ of *A. rossii* have the terminal hairs of their palmate scales longer than those of *A. stephensi*. Some experience is necessary to appreciate this sign.

The " deck " of the egg of *A. rossii* is open and oval; that of *A. stephensi* is narrow and encroached on by the large lateral floats which give the " gunwale " an elongated figure of 8-shape.

A. barbirostris can easily be recognised as a large black Anopheline, the palps and proboscis entirely black without any bands of white. The larvæ are big, black, and lie in an S-shaped curve as a rule. The outer frontal hair is branched and brush-like.

A. jamesi is a small black mosquito; the palps are banded; it is readily recognised by the white " socks " on its hind-legs, *i.e.*, the distal three or four segments of the leg are pure white.

DESTRUCTION OR BIRTH-CONTROL OF MOSQUITOES.

Although it is outside the function of a text-book on Biology, we give a few hints which will enable the student to add much to his comfort and to his health by destroying mosquitoes or preventing them breeding. As the larvæ can exist only in water the simplest plan of campaign is to prevent all unnecessary accumulations of water in the neighbourhood of your dwelling. Pools should be drained or filled up. All useless tins, broken or discarded *chattis*, bottles or other vessels should be removed or rendered incapable of holding even a teaspoonful of water. Water in flower-vases, *chattis*, jugs or other household receptacles should be emptied at least once a week so as to give the larvæ no time to develop. If pools in your neighbourhood be too large to drain or to fill up, a little kerosene sprinkled on the surface to form a thin scum kills the larvæ by blocking

up the openings of their tracheae. Water barrels, cisterns, etc., should be effectively covered. The holes in the lids of water-closet cisterns are usually unnecessarily wide for the lever. They should be draped with gauze or cloth just loose enough to allow the lever to function. Drain traps should have enough kerosene once a week to cover the water surface with a thin scum. Taps should not be allowed to drip. If roof-gutters are not straight rain water collects in the sag; if you cannot straighten the gutter, drill a small hole in its most dependent position. Jungle or excessive vegetation should be burned or removed as it gives cover to adult mosquitoes and prevents small collections of water drying up.

A dark coloured woollen coat hung in a sheltered corner of the room attracts many mosquitoes for their daily rest; each morning they should be treated with a "swatter."

If there are no mosquitoes there can be no malaria, The most practical method for municipal prevention of malaria is the efficient birth-control of mosquitoes.

As soon as children can walk they should be taught to recognise the larvæ; they become most efficient trackers; we have known coolie children of eight years of age find several breeding places before two university graduates found one.

THE FERN PLANT.

Ferns show a considerable amount of morphological differentiation. At one stage in their existence all possess a stem bearing both leaves and roots, the tissues of which show definite histological specialisation. The general appearance or "habit" of a Fern depends largely on the character of the stem, which may be a vertical trunk, ten or twelve feet high as in the Tree Ferns, or it may creep above ground or climb over rocks or the trunks of neighbouring trees. Most commonly it is a *rhizome* or underground stem, easily mistaken for a root from which however it can be distinguished with certainty by the fact that it bears leaves, of which at least the stumps or scars are present if the actual leaves have fallen off.

Before examining the adult plant in detail, we will first study its *ontogeny* or the life history of an individual, so as to get some clue to its evolution or ancestral history.

In the dry season on the back of most fully developed Fern leaves will be found certain brown patches from which can be scraped or shaken a brown powder. The grains of this powder are spores. Like all spores, each is a single cell and in this case surrounded by a double cell-wall.

Fig. 57.
Germinating Spore.

When the spores are sown on damp earth they germinate, the outer cell-wall ruptures and the protoplasm of the cell, covered by the inner coat, protrudes as a filament, which divides by transverse walls into a number of cells, reminding us of Spirogyra.

Almost at once, however, we get a differentiation of both structure and function. The proximal cell gives off a colourless root-hair or *rhizoid* (Gr. *rhiza*, root ; *oidos*, like) which attaches the tiny plant to the soil and absorbs therefrom water and mineral salts, while the distal cells possess chloroplasts and devote themselves to carbon assimilation.

Later on the cells multiply by dividing in both the tansverse and longitudinal planes, so that we get a thin sheet of tissue, only one cell in thickness and usually shaped somewhat like the ace of hearts. Later still, by the growth of its cells in all three dimensions the central portion becomes thickened into a cushion several cells in depth From the under surface of this little self-supporting plant, called the *gametophyte* (Gr. *phyton*, plant ; *gametos*, married, sexual), a number of unicellular root-hairs or rhizoids are given off.

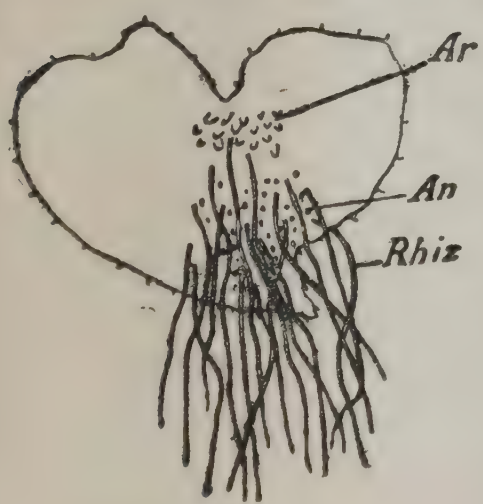

Fig. 58.

Gametophyte of Fern. Ar = archegonia ; An = antheridia ; Rhiz = rhizoid.

In most green-houses or ferneries a plentiful supply of gametophytes in various stages of development can be

found growing on damp bricks or on flower-pots. They can be recognised by their dull green colour, contrasting with the lighter green of the young embryos which may be found growing from the older gametophytes. In size they seldom exceed a quarter of an inch in diameter. In shape they often present a rough resemblance to the ace of hearts. To ensure a supply of gametophytes a number of spores should be sown on a soft piece of tile or brick laid in a saucer of water and kept constantly moist in a shady situation. In dry weather the whole should be covered by a bell-glass.

In cutting sections, you must be careful to remove all earth or sand from the gametophytes or you will ruin both section and razor. For this purpose it is best to sow the spores on the dust of coir refuse, patted down firmly into a flower-pot or saucer and kept constantly damp.

Most fern spores take a long time to germinate and usually some months elapse before the sexual organs are developed.

The gametophytes of most ferns are hermaphrodite, that is to say, the same plant usually bears gonads or sexual organs of both sexes. The male gonads appear early and have generally withered by the time the female gonads are mature so that cross-fertilisation is assured.

Clean a young gametophyte of all earth and sand by moving it to and fro in a basin of water. Place it in water, under-surface upwards, on a slide, and examine with a one inch objective. Note the root-hairs, that the periphery is only one cell in thickness, while the central cushion is several cells in thickness. Search near or between the origin of the root-hairs for the male gonads, called *anthe-*

ridia. They appear as small hemispherical elevations projecting from the surface of the cushion. To get a profile view, fold the gametophytes double in the median line, under surface outwards, and examine the edge of the fold. Later confirm your observations by examining sections.

Each antheridium is formed of two superposed ring-shaped cells, covered by another cell which forms a lid. In the cavity thus formed may be seen several small cells, the sperm-mother-cells. (Fig. 59.)

The *archegonia* (Gr. *arche*, beginning; *gone*, development, womb), as the female gonads are called, must be looked for on older, fully-formed gametophytes on the under surface between the apical notch and the origin of the root-hairs. Each is somewhat flask-shaped, the body or *venter* (Lat. belly) being sunk in the tissue of the cushion, while the long *neck*, the wall of which is composed of four rows of colourless cells in four tiers, projects from the surface. The contents of the flask, filling its cavity, are a large naked egg-cell or ovum, and above it two granular canal-cells, which later on break down into a refractive mucilage.

Profile views should be taken of the archegonia by folding the gametophyte. Note the chimney-like projection of the neck, the granular canal cells in the young achegonia, the refractive appearance of the mature unopened, and the gaping mouth of the opened archegonia. You can scarcely see the ovum except in sections.

To see the opening of the gonads and the process of fertilisation, some quite young gametophytes bearing antheridia, and some others fully-formed with various stages

of archegonia, should be kept moderately dry by omitting to water them for several days, and then placed together in water on a large slide and watched with a one inch or a half-inch objective. Watch an antheridium and you may see the lid-cell rupture and the sperm-mother-cells come out. These remain quiet for some time and you can recog-

Fig. 59.
Antheridium after discharge of spermatozoids.

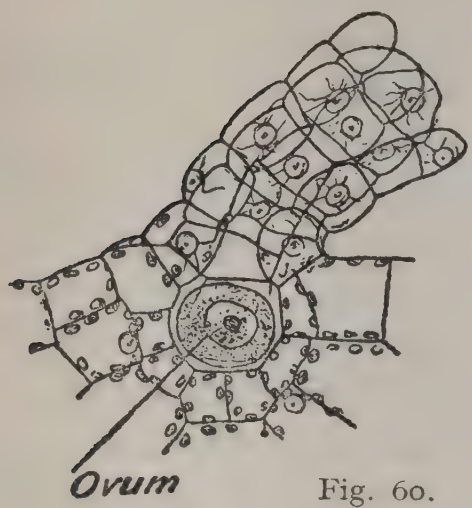

Fig. 60.
Archegonium opened.

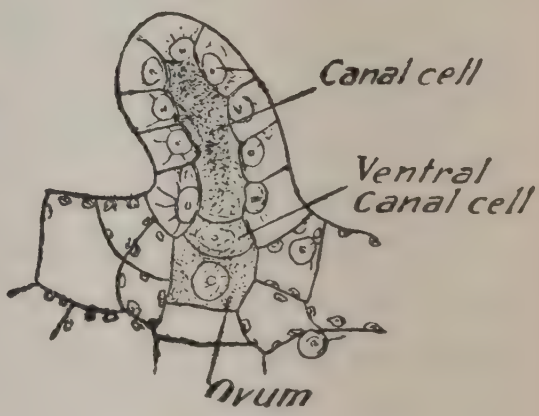

Fig. 61.
Archegonium un-opened.

nise in each the coiled thread of a spermatozoid surrounding a number of fine granules. The walls of the mother-cells dissolve in the water, the spermatozoid sets itself free with a jerk, and lengthens owing to the coils separating. They rotate and swim about so rapidly that at first it is difficult to make out their structure, but in about a quarter to half

an hour their movements become much slower and finally cease. They can be artificially made to slow their movements by putting them in a tenacious medium such as a 10 % solution of gum arabic. They can be killed and stained by weak iodine solution. They are then seen to be composed of a cork-screw-like band of nuclear material. They bear a number of cilia or flagella at their anterior end, and at their posterior end for some time a thin vesicle containing small starch granules, stained blue by the iodine, in contrast with the brown of the nuclear spiral and the flagella.

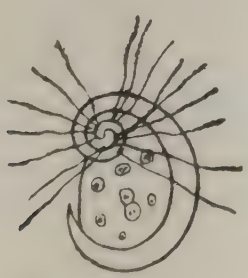

Fig. 62.

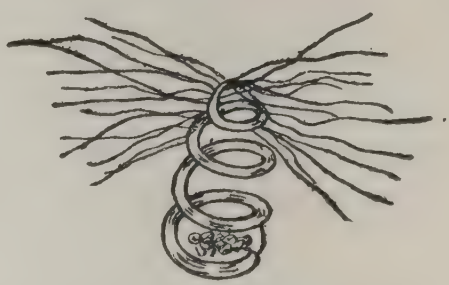

Fig. 63.

Spermatozoids of Fern.

Permanent specimens are best made by fixing in the vapor of osmic acid, or by running in a drop or two of 1 per cent. osmic acid solution. After washing, stain with logwood or fuchsin-iodine-green and mount in balsam. To observe the opening of the archegonia and the process of fertilisation, mount on the same slide in water both full-grown and young gametophytes which have not been watered for some time.

The archegonia nearest the notch are the youngest and their neck cells probably look granular. The oldest archegonia, possibly already fertilised, possibly opened and dead,

a withered brown colour inside, are to be found nearest the root-hairs. Between these too old and too young archegonia will be found those ready to open and become fertilised. You will recognise them by the strong refraction of the contents of the neck. Watch such a one and you will be rewarded by seeing the four apical cells of the neck suddenly separate from one another, leaving a wide mouth through which the mucilage resulting from the breaking up of the canal-cells, escapes intermittently.

If there be any spermatozoids swimming about you will observe that though they took no notice of the archegonium before it had opened, they now swim toward it from a considerable distance and enter the neck. Here their movements are slowed by the mucilage as in your experiment with gum arabic. You will notice that the vesicle at the posterior end of the spermatozoid is left outside the neck.

Although several spermatozoids may enter the neck only one succeeds in wriggling down and fertilising the ovum. The resulting zygote soon surrounds itself with a cell-wall so that any later-coming spermatozoids cannot enter.

In the mucilage formed by the canal-cells is to be found a small amount of malic acid, and it seems that this substance has the power of attracting the spermatozoids.

Heat to redness in a Bunsen flame a narrow piece of glass tubing and draw it out into a very fine capillary tube. Into a short piece of this capillary tube draw some solution of malic acid and malate of potash, each 0.02 per cent. Seal one end in the flame, place the open end on the slide under a cover-glass in some water in which spermatozoids are

present, and you will find they all swarm into the tube. This is a good example of sensitivity to chemical attraction or *chemiotaxis*, as it is technically called.

DEVELOPMENT OF THE EMBRYO SPOROPHYTE.

After fertilisation the zygote forms a cell-wall of cellulose and soon divides into two cells which again divide and re-divide to form successively four and eight cells. In most Ferns in about a week or a fortnight after fertilisation the venter of the archegonium is found distended by this little embryo, while the neck has become brown and withered.

Of these eight cells one multiplies to form the growing point of the stem, two others of the upper cells multiply to form a mass of parenchymatous cells called the *foot*, an organ peculiar to the Fern phylum. This is imbedded in the tissue of its parent gametophyte and absorbs from it nourishment for the young embryo till it is able to take care of itself.

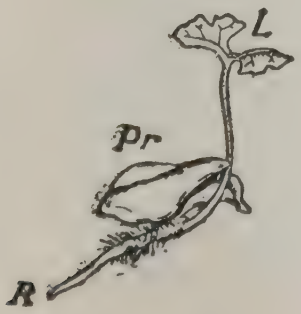

Fig. 64.

Embryo attached to gametophyte, Pr.; R = Root; L = first leaves.

Of the lower cells two develop into the primary leaf while another grows down to form the primary root. As the little plant grows the young stem develops and forms leaves,

the root attaches it to the soil. The foot and gametophyte wither away as the need for their services ceases to exist.

The Mature Sporophyte.

NAKED EYE CHARACTERS.

As already mentioned the Fern plant in the spore-bearing stage consists of root, stem and leaves, which are lateral organs of the stem. The habit or external appearance of the different genera and species depends greatly on the character of the stem.

The following description, unless otherwise stated, will apply to the genus *Nephrolepis*, *Nephrodium* or *Aspidium*, species of which are common in gardens all over India. Dig up a well grown plant of *Aspidium* and wash the earth from its roots.

Note the short unbranched stem growing obliquely upwards, its surface covered by the stumps of fallen leaves. Above these stumps are the stalks of this year's fully developed leaves. Above these are next year's leaves curled up from apex to base in what is called *circinate* vernation. Note that these as well as the bases of the older leaves are thickly covered with yellowish scales easily brushed off with the finger. Nearest the apex of the stem may be seen still smaller rudimentary leaves which will become fully developed two years hence. Thus we learn that the leaves take three years to attain full development.

Examine a fully developed leaf. Note that it is composed of a long *leaf stalk* or *rachis*, nearly cylindrical, except for two longitudinal lateral ridges. From these ridges are given off on each side the leaflets or *pinnae* (Lat. feathers

wing). Note that the leaf veins bifurcate. This forked venation is a characteristic of Ferns by which many imperfect fossil remains can be recognised.

Late in the season circular brown patches will generally be found on the under surface of the pinnae. Each of these is a *sorus* (Lat. a collection), a group of several spore-cases or *sporangia*, covered by a thin kidney-shaped membrane, the *indusium* (Lat. a lady's under-garment), derived from the epidermis of the leaf.

Note the roots which arise not only from the stem but from the bases of the leaf-stalks. They are therefore adventitious roots. Note also that you cannot recognise any persistent indication of the primary root of the embryo.

Trim off the leaf-stalks about 6 or 8 mm. from their insertion on the stem. Cut off 30 or 40 mm. of the older end of the stem by an accurately transverse cut, and boil in 20 to 30 per cent. hydrochloric acid till the ground tissue becomes soft.

Examine the cut surface of the other piece of the stem and note that the periphery of the section is a dark brown band of *sclerenchyma* surrounding the *ground tissue* of yellowish white parenchymatous cells. Seven or eight larger yellow dots will be seen arranged in a ring some distance from the centre (Fig. 65). These are the *steles* or vascular bundles. Outside these are scattered smaller yellow dots, the *leaf-traces*, or vascular bundles running to the leaves.

Fig. 65.

Aspidium. Transverse section of stem. Black line=Sclerenchyma. Shaded parts=Vascular bundles.

Split the upper inch of the stem including the apical bud into two equal halves by a median longitudinal section.

Note that the large steles do not form continuous lines but are interrupted at intervals—the foliar gaps. One or two of the leaf-traces may be seen to arise from the stele and run into the base of the leaf stalk ; if not, a little dissection by picking away the ground tissue should be made to demonstrate this continuity. Take the piece of stem you have boiled in hydrochloric acid, and after careful washing, pick away with the point of a knife and by brushing with a nail-brush, all the softened ground tissue so as to leave bare the vascular skeleton of the steles. Note that it forms a cylinder of trelliswork like a clothes "jamp," of which each mesh is opposite the insertion of a leaf and is called a "foliar gap" (see Fig. 67)

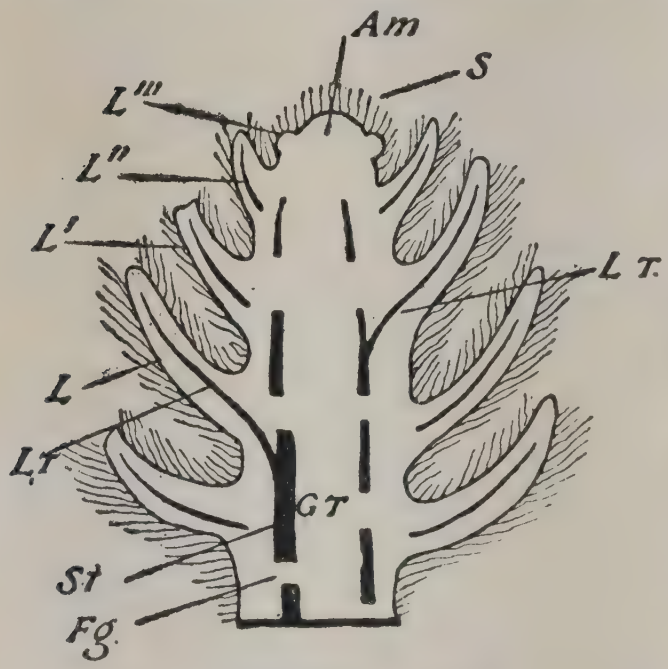

Fig. 66.—Longitudinal section of stem. Am=Apical meristem ; G.T.=ground tissue; Fg. =foliar gap ; L=this year's leaf ; L′= next year's leaf ; L″ and L‴=rudiments of leaves of following years ; L. T=leaf-trace ; St=stele.

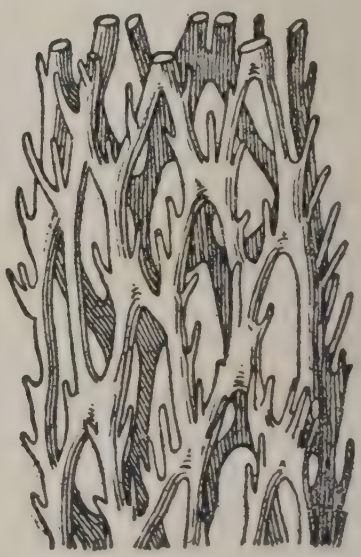

Fig. 67.

Vascular skeleton of stem of Aspidium.

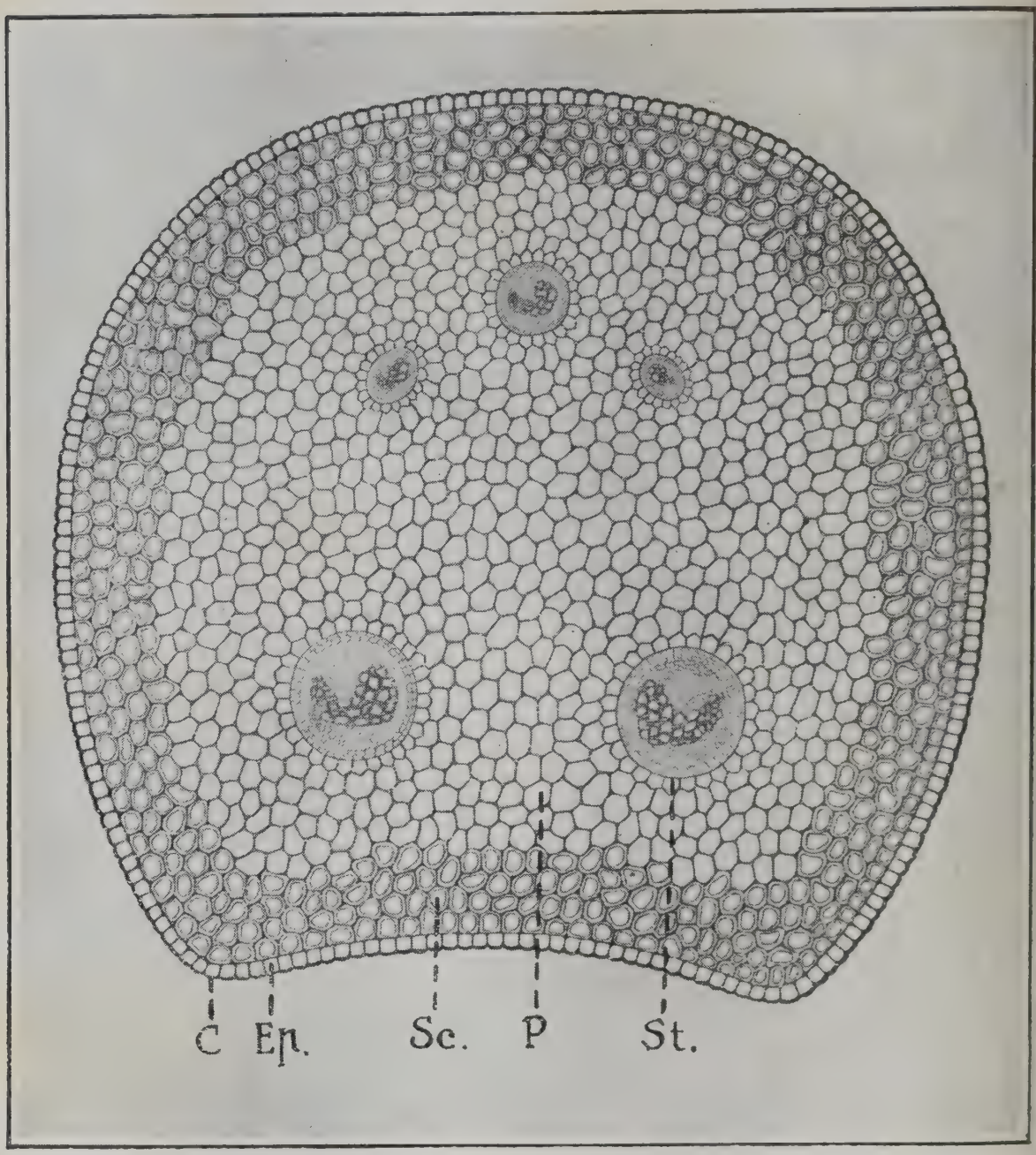

Fig. 67A.—*Transverse Section of Rachis of Nephrolepis.*

C.—Cuticle.
Ep —Epidermis.
Sc.—Sclerenchyma.
P.—Parenchyma.
St.—Stele.

To face page 213.

Make some thickish longitudinal sections of the stem, boil them in nitric acid to which a few crystals of chlorate of potash are added. This should be done in the open air or in the verandah, as the fumes of the acid will corrode the metallic instruments in the laboratory. Wash the sections with several changes of water, tease the tissues with needles into minute fragments, mount in water and examine first with a low, then with a high power of the microscope. By this method the pectin which constitutes the so-called " middle lamella " between the cells of the tissues, is dissolved so that they can readily be separated from one another by teasing.

Cut as thin as you can both longitudinal and transverse sections of the stem from material that has been preserved in alcohol. It is important that the sections be not oblique, but cut accurately at right angles to, or parallel with the axis of the stem. Do not try to make a transverse section of the complete stem as it is too big; be satisfied with cutting a small area at a time, provided the section is *thin and in the right plane*. Mount some of your thinnest sections in glycerin others in chloro-iodide of zinc solution.

Microscopic examination of these sections and of the macerated and teased cells shows that there is—

(*a*) An outer badly defined *epidermis*, composed of a single layer of cells with dark brown outer walls, bearing here and there *scales* one layer of cells in thickness.

(*b*) Internal to this is the *ground tissue*, the inner central mass in which the steles are imbedded. It consists of cells with thin cellulose walls con-

taining starch. In the central portion are many intercellular spaces.

(*c*) In the outer portion of the ground tissue is a ring of *sclerenchyma* composed of elongated cells with thick, brown, lignified walls dotted with pits. In longitudinal sections they are seen as long fibres with tapering ends. There are no intercellular spaces.

(*d*) The steles.

It is easier to cut good sections from the base of the leaf-stalk as there is not so much hard *sclerenchyma*. The tissues in general resemble those of the stem while the structure of the stele is the same. As the student can cut thinner and better sections from the leaf-stalk, he is advised to use it for study of the minute structure of the stele.

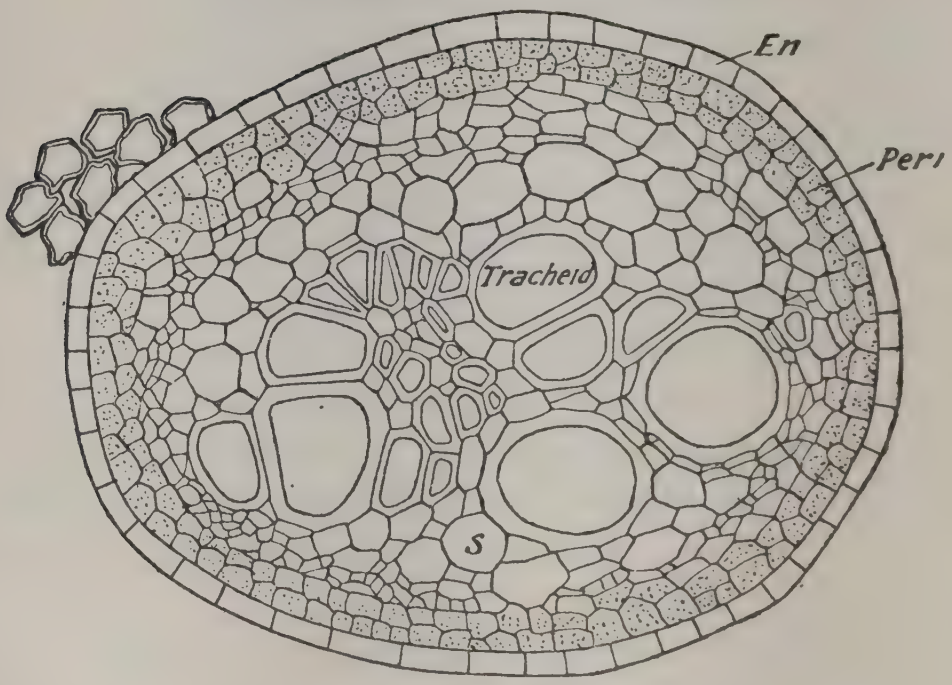

Fig. 68.
Stele of Aspidium.
En=endodermis ; Per_i=pericycle ; S=Sieve-tube.

Examine a stele or vascular bundle with the $\frac{1}{6}$th objective and note that each is surrounded by a sheath or *endodermis*, a single layer of cells with yellow walls, yellow contents and no intercellular spaces. Internal to this is the layer called the *pericycle*, two* cells in thickness, the cells being rounded, with thin cellulose walls enclosing protoplasm with starch, and for this reason sometimes called the *starch-sheath*. (Fig. 68. peri.)

Internal to this is the *phloem* or *bast* consisting of—

(*a*) Sieve-tubes which in transverse section appear polygonal and in longitudinal sections are seen to have sieve plates arranged along their side walls. The tubes are lined with a thin layer of granular protoplasm. (Fig. 68. S.)

(*b*) The bast-parenchyma composed of thin-walled cells rich in protoplasmic contents.

In the centre of the bundle is the xylem (Gr. *xylon*, wood) or wood, consisting of (*a*) starch-containing cells, the *wood parenchyma*, and (*b*) *tracheids* which in transverse section at once catch the eye as large oval or polygonal spaces from which the protoplasm has completely disappeared. In longitudinal section they are seen to be wide empty tubes, their walls are lignified and have transverse markings like the rungs of a ladder owing to the walls being unequally thickened. For this reason they are called *scalariform tracheids*. (Lat. *scala*, a ladder). (See page 230.)

They fit against one another by their obliquely bevelled ends. As a rule these ends are not actually perforated in Ferns, and so they are called tracheids, *i.e.*, single tube-like

* In some Ferns only one.

cells. Should they be perforated and a communication be formed between two or more cells, this constitutes a true *vessel* or fusion of tracheids characteristic of the Angiosperms.

Fig. 69.

Portion of a Scalariform Tracheid.

At one or two spots may be seen spirally thickened tracheids which as they were the first formed, are known as the *protoxylem* (Greek for "primitive or first wood.")

The arrangement of the sclerenchyma and of the vascular bundles varies much in the Fern family. The arrangement above described is that common in Ferns with erect or ascending stems. In climbing stems there may be several narrow black strands of sclerenchyma. In *Pteris*, well described in many English text-books, in addition to the peripheral, there is an incomplete large brown ring of sclerenchyma half-way to the centre of the stem enclosing two or three large central steles. In Davallia there is no sclerenchyma; of the bundles which form a ring, one on the upper surface and another on the lower, are much larger than the rest.

In the very young stems of most Ferns there is a single central stele, a condition which persists in the *Hymenophyllaceæ*.

Clear away from the apex of a stem the leaf-stalks and young leaves, carefully pick away with forceps as many as you can of the scales which cover the extreme tip. With a camel-hair brush clean off all the scales that remain. With a lens you can now see the *growing point* or *apical cone.* A number of these should be fixed in alcohol, embedded and cut in transverse and longitudinal sections, preferably with a microtome, though good sections may be made with a razor even from fresh tissue held between the finger and thumb, Longitudinal sections passing accurately through the axis of the stem show that a short distance from the apex all the tissues of the stem, stele, ground-substance, sclerenchyma and epidermis, merge into a white tissue composed of undifferentiated parenchymatous cells resembling those of the embryo and like them capable of multiplication. Such a tissue is known as *meristem.* (Gr. *meristes,* a divider).

The exact apex of the cone is occupied by a wedge-shaped cell, *the apical cell,* which in Aspidium and other Ferns with vertical stems is a three-sided pyramid with its apex sunk

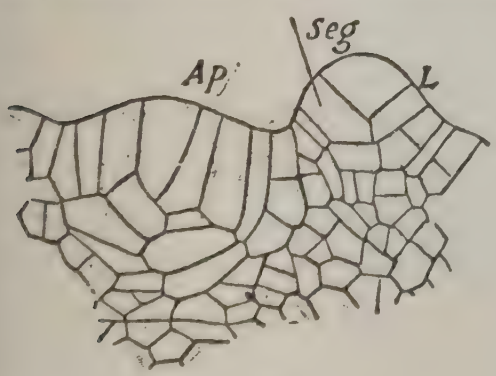

Fig. 70.

Longitudinal section of growing point; of stem to left, of leaf to right L.

Ap=apical cell; Seg=Segmental cell.

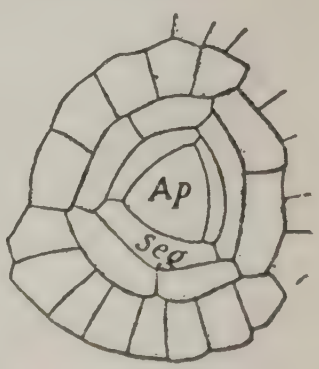

Fig. 71.

Transverse section of growing point.

in the tissue, toward the stem, its convex base outwards. The cells surrounding this have been cut off from it in cell-division by walls parallel to its three sides. These are called the *segmental cells*, and these again undergo division to form the apical meristem. All the cells of the stem and leaf have been derived from the apical cell by multiplication and differentiation.

If the sections of the apical cone be too opaque to show their structure they should be "cleared" by placing in *eau de Javelle* which dissolves out the protoplasm leaving the cell-walls sharply defined. The sections are then washed and mounted in water, not in glycerin. If too transparent, the outlines of the cells can be restored by alcohol or they may be lightly stained with safranin. If you have no *eau de Javelle*, the sections can be cleared with strong solution of potash.

THE ROOT.

The roots are thin and brown, except at their apices where they are more transparent. Longitudinal and transverse sections should be made from the thickest part of an old root.

The general structure of the fern root resembles that of the root of flowering plants. In a transverse section we see externally a single layer of cells from which the *root hairs* grow out; it is therefore called the *piliferous layer*. (Latin *pilus*, a hair; *fero*, to bear).

Internal to this is the *cortex* or *ground tissue*, of which the outer portion consists of thin-walled parenchymatous cells, the inner of thick-walled sclerenchyma.

Internal to this is the *endodermis*, a single layer of narrow cells enclosing a *pericycle* of two layers of thin-walled cells containing protoplasm.

In the centre we find the vascular bundles. In all roots, not only of the Fern phylum but of the flowering plants also, we find the xylem and phloem groups alternating with one another in contrast to their arrangement in the stem. In the Fern we find two groups of *xylem* opposite one another, the largest tracheids being those nearest the centre.

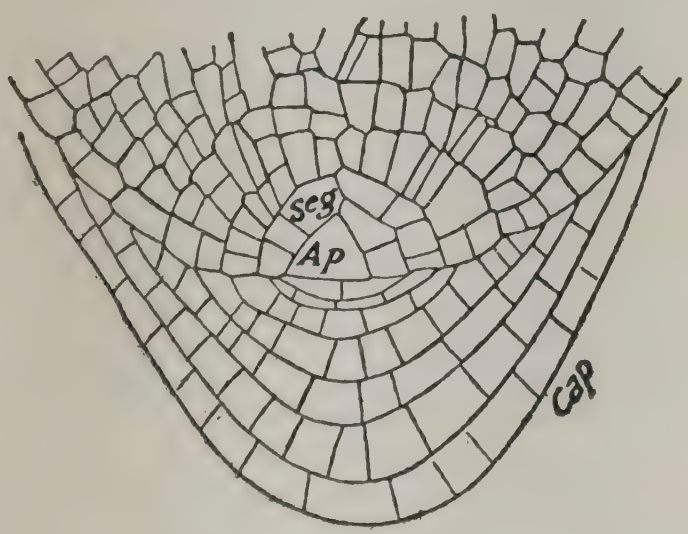

Fig. 72.
Growing point of Fern root.
Ap=apical cell; Seg=segmental cell.

Two groups of *phloem* consisting chiefly of sieve-tubes like those of the stem, alternate with the strands of xylem instead of the concentric arrangement seen in the stem.

In the endodermis, at opposite points in the same diameter as the xylem strands, may be seen one or two cells larger than the rest; these are the *root-forming cells* from which the young lateral rootlets develop.

THE ROOT APEX.

Examine the apex of the root and observe it is covered with a *root-cap*. (Cap. Fig. 72.)

Embed in paraffin the apex of a root that has been fixed in alcohol, cut thin median longitudinal sections, mount in glycerin. One or two of these sections, which have passed through the exact anatomical apex will show a large tetrahedral *apical cell*, looking triangular in section with its apex directed toward the older part of the root. Around this are the *segmental cells* that have been successively cut off to form the apical meristem, like that of the stem with the important difference that cells are not only cut off from the sides of the pyramid to form the body of the root, but also from its base to form the root-cap. The function of the root-cap is to protect the delicate growing point. As it bores through the soil the outer cells are constantly being rubbed off and replaced by the new cells cut off from the base of the apical cell.

A good general idea of a root-cap can be obtained from the large caps on the aerial roots of the Screw Pine.

THE LEAF.

Several steles run as "leaf-traces" from the stem to the rachis whence lateral ones run out to each pinna and there break up to form the characteristic forked veins.

To see their minute structure cut several narrow strips about 3 or 4 mm. wide, from pinnae free from sori. Sections should be made from both fresh tissue and that preserved in alcohol which not only fixes the protoplasm but dissolves out the chlorophyll. Place several of these strips together like the leaves of a book for mutual support, place in a slit in a piece of carrot and cut sections, both parallel to and at right angles to the long axis of the leaflet. Mount

some of the thinnest section directly in glycerin and others after treating with iodine.

Hold a fresh piece of a pinna with the thumb and middle finger over the index of your left hand and peel off the epidermis from both the upper and lower surfaces. A very small piece will suffice. Mount in water and examine with your high power.

Note that the epidermis of the upper surface is composed of a large number of cells of very irregular outline placed in close contact with one another like the pieces of a jig-saw puzzle. They contain a few chlorophyll bodies in their otherwise colourless protoplasm. There are no intercellular spaces between them. The outer surface of the epidermal cells forms a thin waterproof *cuticle*. The epidermis of the lower surface resembles that of the upper except that we find a number of *stomata* (Gr. stoma, a mouth or opening.) Each stoma is an opening on the surface of the leaf allowing air to communicate with the intercellular air-spaces of the tissues. Each is bounded by a pair of kidney-shaped *guard-cells* with their concavities facing one another.

The guard-cells present a marked contrast to the other cells of the epidermis not only in their size and shape but also in colour as they contain many more chloroplasts. The size of the stoma is regulated by the turgidity of these guard-cells. If the plant be rapidly absorbing water, as on a moderately warm day with good sunshine, the cells become turgid, the stoma is enlarged and watery vapor is freely transpired. If on the other hand the absorption of water be lessened, the guard-cells become flaccid and their free concave margins approach one another and close the stoma. This regulation of the size of the stoma can be

understood by the help of diagram, Fig. 74, in which the shaded portion represents the flaccid cells almost closing the stoma, while the thick dark line represents the same cells in their turgid condition, leaving a wide space between them.

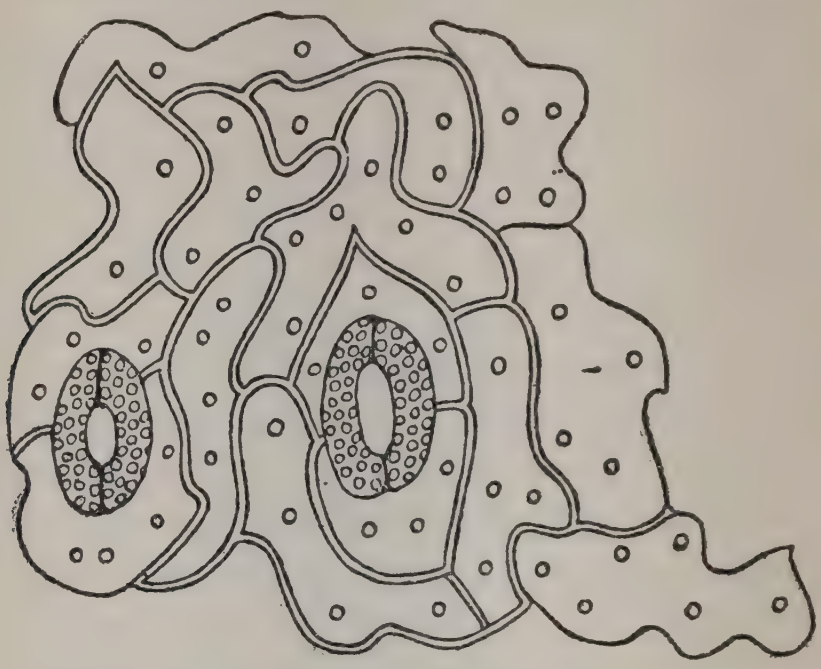

Fig. 73.
Epidermis of Fern leaf showing two stomata.

Fig. 74.

In the sections note that the space between the upper and lower epidermis is occupied by *mesophyll*, here and there traversed by vascular bundles. The cells of the mesophyll are thin-walled and contain many chloroplasts; those near the upper surface have small intercellular spaces; those near the under surface are more irregular in shape and separated by large intercellular spaces.

Note that the Ferns being older and more primitive than the flowering plants, we do not find so great differentiation in the structure of the leaves. For example the differentiation into spongy and palisade layers of the mesophyll is not well marked, the epidermal cells have not yet lost all their chlorophyll, and the vascular tissue instead of true vessels contains tracheids. Each leaf is green and usually bears spores, fulfilling both vegetative and reproductive functions, which in the higher flowering plants are carried out separately on specially modified leaves, the foliage leaves and the sporophylls respectively.

Examine a sorus with a low power and note that it is composed of a large number of sporangia covered by the *indusium*, a sheet of epidermal cells. In some Ferns, such as Pteris and the Maiden Hair, instead of an indusium, the sori are protected by the margin of the leaf folding over them. In Polypodium and others the indusium is absent and the sori naked. Scrape off some *sporangia* and mount in water. Each is composed of a stalk and a hollow capsule shaped like a bi-convex lens. The brown cells of which the capsule is formed are thin and membranous except round the margin where they are peculiarly thickened and form the *annulus* or *ring*. The inner and the contiguous portions of the lateral walls of the cells forming the ring are dark brown and greatly thickened while the free outer portion is thin and yellow. In dry weather the annulus loses its moisture and straightens out, thus rupturing the capsule and discharging its contents, the *spores*. This rupture can be seen by placing some ripe sporangia on a slide and gently heating it over a lamp. Rapidly place

it on the microscope and you will see the process take place. The same result can be obtained by mounting in glycerin

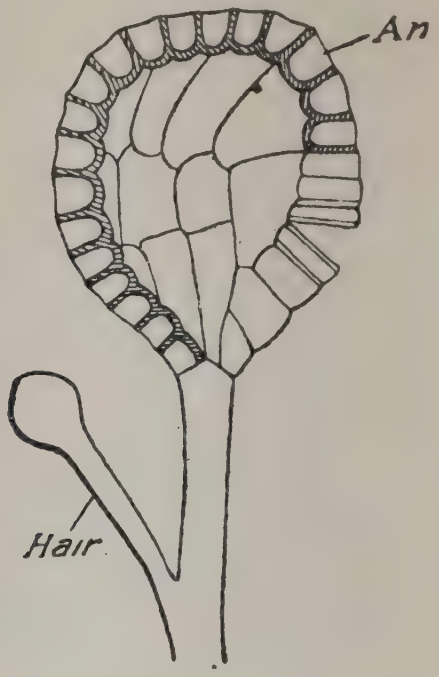

Fig. 75.
Sporangium of Aspidium. An=annulus.

which will extract the water from the annulus. Examine the spores with a high power. Each is composed of a single cell enclosed in a double cell-wall. The outer wall is cutinised and marked by an irregular net-work of raised rough lines.

KARYOKINESIS.

Although he has not yet sufficient knowledge of microscopical technique to verify the facts for himself, it is now necessary for the student to learn something about the method of nuclear division already frequently referred to as *karyokinesis* (Gr. *karyon*, a nut or nucleus; *kinesis*, movement) or *mitosis* (Gr. *mitos*, a thread).

The essential part of the phenomenon is that shortly before dividing to form two daughter-nuclei, a portion of the nucleus called the *chromatin*, (Gr. *chroma*, colour) from the fact that it stains deeply with certain dyes, arranges itself in loops or rods called *chromosomes*, (Gr. *soma*, body.) The number of these chromosomes may be as few as two or as many as over two hundred, but is always constant in any one species of animal or plant.

In the ordinary process of division each chromosome splits longitudinally into two halves. The halves of each chromosome separate from one another and move, or are drawn, to opposite poles of the mother-nucleus to form the two new *daughter-nuclei*. Thus each new cell possesses not only the same number of chromosomes in its nucleus, but the same quality of chromosomes, as it has a half of each chromosome of the mother cell, and it is reasonable to believe that each daughter chromosome possesses the same functions and attributes—whatever they may be—as its parent.

A striking modification of this process takes place during the formation of the reproductive cells such as the gametes of animals—spermatozoa and ova,—and the spores of the higher plants—Mosses, Ferns and Flowering Plants.

For instance in the spore-mother-cells of the Fern after certain manœuvres, half of the chromosomes without splitting go to one pole, the other half go to the opposite pole of the mother-nucleus and there form the daughter-nuclei, which have now *only half as many chromosomes as the spore-mother-cells and all the body cells of the sporophyte plant.* The chromosomes of the daughter-cells at once split into longitudinal halves, half of each going to form the nucleus of the grand-daughter-cells which are the spores.

The result of this, hence called, "reducing division," is that the nuclei of the spores of Ferns, also of Flowering Plants, pollen-grains and embryo-sacs, of the spermatozoa and of the mature ova of animals contain only half the number of chromosomes found in the "vegetative" or body cells of their parent. Only by the conjugation of the gametes of sexual cells is the original double number restored. In the case of animals this takes place at once, as the mature ova and the spermatozoa do not develop further unless they meet and conjugate. In their case the sperm and ovum are the only cells which (except in cases of disease) contain the reduced number of chromosomes.

In the Moss, Fern and Flowering Plant the spore divides to form the cells of the gametophyte. It cannot increase the number of its chromosomes so that *all the cells of the gametophyte contain only half the number of chromosomes found in the cells of the sporophyte.* There is no need therefore

for a reduction division in the formation of the pro-nuclei of the spermatozoids and ova of the Fern or Flowering Plant. As a result of the conjugation of these two gametes the number of chromosomes in the zygote nucleus is doubled, and this double number remains constant throughout all the cells of the embryo and adult sporophyte till in the formation of the spores a reducing division again takes place.

ALTERNATION OF GENERATIONS.

In our review of the life-history of the Fern we have seen that it passes through two generations, a sexual and an asexual, which occur in regular alternation. Twice in its life-history does it pass through a unicellular stage. The asexual generation—"the Fern plant" as popularly recognised, gives rise to asexual spores, and is hence called the *sporophyte* (Gr. *phyton*, a plant), which in turn give rise, not directly to a large sporophyte, but to the little prothallus, or sexual generation which, from the fact that it bears the gametes, is known as the *gametophyte*. The fertilised ovum or zygote gives rise in turn to the sporophyte. The number of chromosomes in the cell-nuclei of the sporophyte is double that in the nuclei of the gametophyte, the reduction taking place in the division of the spore-mother-cells. By the fusion of the gamete nuclei the double number is restored in the zygote.

This regular alternation of a sexual with an asexual generation is characteristic of all the higher plants, though owing to the diminution in size of the gametophyte phase in the higher Flowering Plants it can only be recognised by the aid of the microscope.

FLOWERING PLANTS.

I. CYCAS.

The Oak, the Banyan and the Sequoia may have rival claims to the title of Monarch of the Forest, but among the flowering plants there is none to dispute that the Cycads are the absolute Aristocrats. Away back in the Permian period we find fossil Cycads differing but little from those of our own time. Like many an old human family, the Cycads have failed to adapt themselves to their changing environment, with the inevitable result that they have lost much of their first estate and are gradually dying out, making way for more enterprising or accommodating upstarts who push them aside and usurp their place in the struggle for existence.

They were the first flowering plants to appear on the earth and had so covered the greater part of its surface during the Mesozoic age that it is sometimes called the "Age of Cycads."

England and Europe generally, which were at that period covered with dense forests of Cycads, do not at the present day contain a single indigenous tree. Cycads are now comparatively few in number and restricted to certain tropical and sub-tropical regions.

Cycas is a handsome evergreen tree, seldom exceeding twelve feet in height, so much resembling a Tree Fern or Palm in habit that Europeans often erroneously call it a "Sago Palm." The trunk is, as a rule, unbranched like that of a Palm and bears at its apex the leaves arranged

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Fig. 76.—Cycas circinalis, Female Tree.

in a rosette. The tree is diœcious, that is to say, the male and female spores are borne on separate plants. In the full-grown female tree a zone of carpels or macrosporophylls is usually produced alternately with a ring of foliage leaves as is seen in Fig. 76. The stem is cylindrical, its surface rough with scaly leaves and the stumps of fallen foliage leaves. Though usually unbranched, it contains a number of dormant buds which often sprout out close to the ground, and are utilised by the *mali* as a means of reproducing the tree.

The histological structure of the stem agrees in the main with that of the Dicotyledons. Among the latter we can find stems of more convenient bulk, so the student may postpone this portion of his study till he is familiar with the histology of the dicotyledonous stem. (See p. 280.)

The stem of Cycas contains a large amount of *central ground tissue* or pith, composed of parenchymatous cells containing much starch from which an inferior sort of sago can be made. External to the pith we find the vascular bundles arranged as a circle of wedges with their apices pointing inwards. These bundles are collateral and open, that is to say, there is a layer of *meristem* or *cambium* separating the *wood* on the inside from the *phlœm* or bast on the outside. From this layer of cambium, wood is continually being formed on the inside, and phlœm on the outside. Between the vascular wedges are the *medullary rays*, layers of ground tissue connecting the pith with the parenchyma of the cortex. As the stem grows a little older, the layer of cells in the medullary rays between the cambium of the bundles acquires the power of growth, giving off woody tissue

on its inner aspect and phlœm on its outer, so that we get complete cylinders of cambium, wood and phlœm, which in a transverse section of the stem appear as rings. This meristem is known as the *interfascicular* cambium.

After a few years this normal ring of cambium becomes exhausted, but a new meristem arises in the pericycle, and forms bast externally and wood internally. This secondary meristem in its turn becomes exhausted and is followed in turn by new layers.

The wood of Cycas differs from that of Dicotyledons in that it contains only tracheids. A tracheid (Greek, *trachelos*, a tube, *oidos*, like) differs from a vessel or trachea in that it is formed of a single elongated cell, while a vessel is formed by the union of several cells joined end to end. These tracheids are marked by dots and bordered pits which are mostly rounded, but may be elongated, in which case they give the cell a ladder-like appearance and are called scalariform tracheids (Latin, *scala*, staircase). The pits are areas in which the cell-wall remains unthickened, consequently such areas appear bright when examined under the microscope. The bordered pit gives the appearance of two concentric circles, which is due to the fact that the pit is overhung by a dome-shaped thickening, the inner smaller ring represents the opening in the centre of the dome, the outer larger circle indicates the margin of the dome. In the first formed wood some tracheids with spiral thickening are to be seen.

The phlœm differs from that of the Angiosperms in that there are no companion-cells but only sieve-tubes and parenchyma as in the Ferns.

The cortex is remarkable for the large number of mucilage ducts which it contains, they are also found in almost all parts of the plant though in fewer numbers than in the cortex.

THE ROOT.

The radicle of the seed persists, growing vertically downwards as a tap-root which like its branches, increases in length by means of an apical growing point covered by a root-cap and in its general features resembles the Dicotyledons.

THE LEAVES.

The leaves of Cycas are of three kinds, scale leaves, foliage leaves and sporophylls.

We have already seen the scale leaves which help to give the stem its rough appearance. Longer scale leaves may be seen in a whorl covering the inflorescence before it reaches maturity. The scale leaves are all dry and brown owing to the absence of chlorophyll.

Fig. 77.
Carpel of Cycas circinalis.

The foliage leaves are large and pinnate (feather-shaped) with a central *rachis* to which the linear *pinnæ** are attached on each side. In the bud each of these pinnæ is soft and coiled up from apex to base in *circinate* fashion. Note that the pinnæ near the

* *Latin*, pinna, a feather.

base of the leaf cease to expand, developing into hard and sharp-pointed *thorns*, while the more distal pinnæ are flattened in the horizontal plane and become leathery in consistence. A transverse section of a pinna shows a vascular bundle surrounded by a pericycle of colourless cells, entering the mid-rib of the pinna from the rachis. The surface of the leaf is covered by a single layer of *epidermal* cells with thick cutinised walls. Split a short portion of a pinna horizontally and boil the pieces for a minute in nitric acid to which a few crystals of chlorate of potash are added. This will macerate the tissues and cause all the tissues of the leaf to separate into their constituent cells, except those which are cutinised, as cutin resists the action of this fluid. Wash the *debris* and mount in water the epidermis which remains entire as a thin film. Note that the elongated cells on the upper surface of the leaf form a mosaic, their margins in contact with no interspaces. On examining the under-surface you will find numerous *stomata* at the bottom of pits formed by from ten to twenty elongated cells.

Below the epidermis we come on a layer of thick-walled sclerenchymatous cells to which the leaf owes its leathery consistence. This layer varies in thickness from five or six cells on the under-surface of the mid-rib, to one on the upper surface of the lamina.

Below thes clerenchyma we come upon the *mesophyll*, or chlorophyll-containing tissue. This consists of an upper one-celled *palisade*, and a lower *spongy* layer. The upper layer receives its name from the fact that its component cells which contain many rounded chlorophyll bodies, are columnar in shape, five or six times as long as they are broad

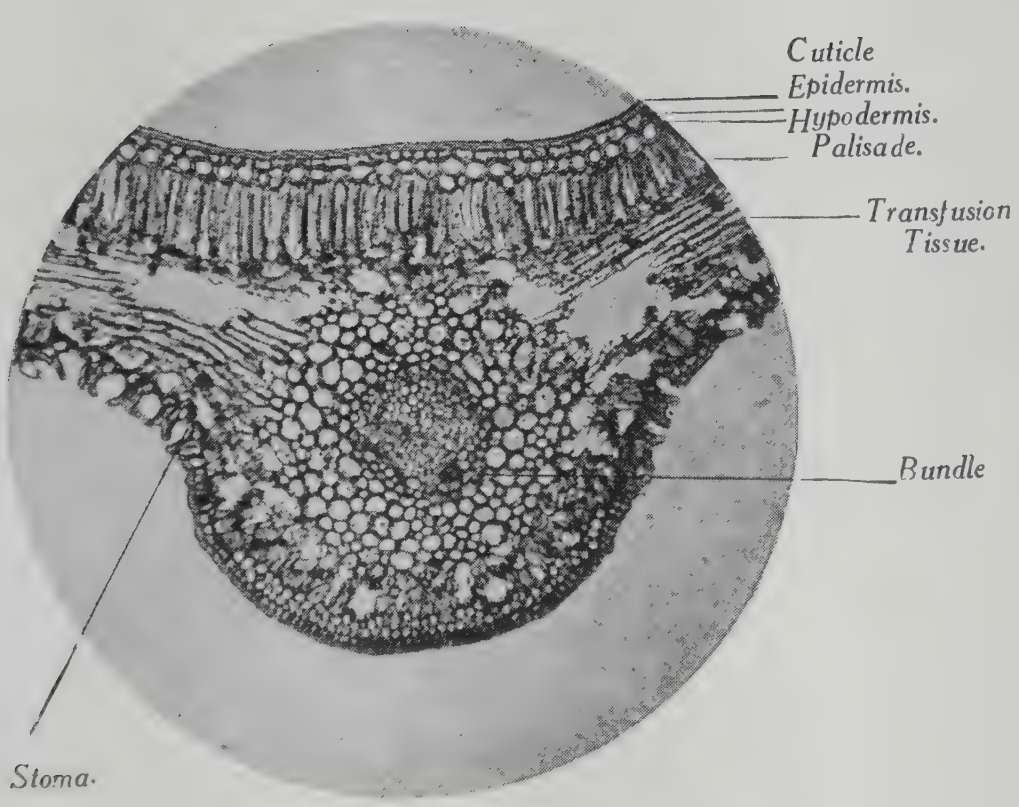

Fig. 78.

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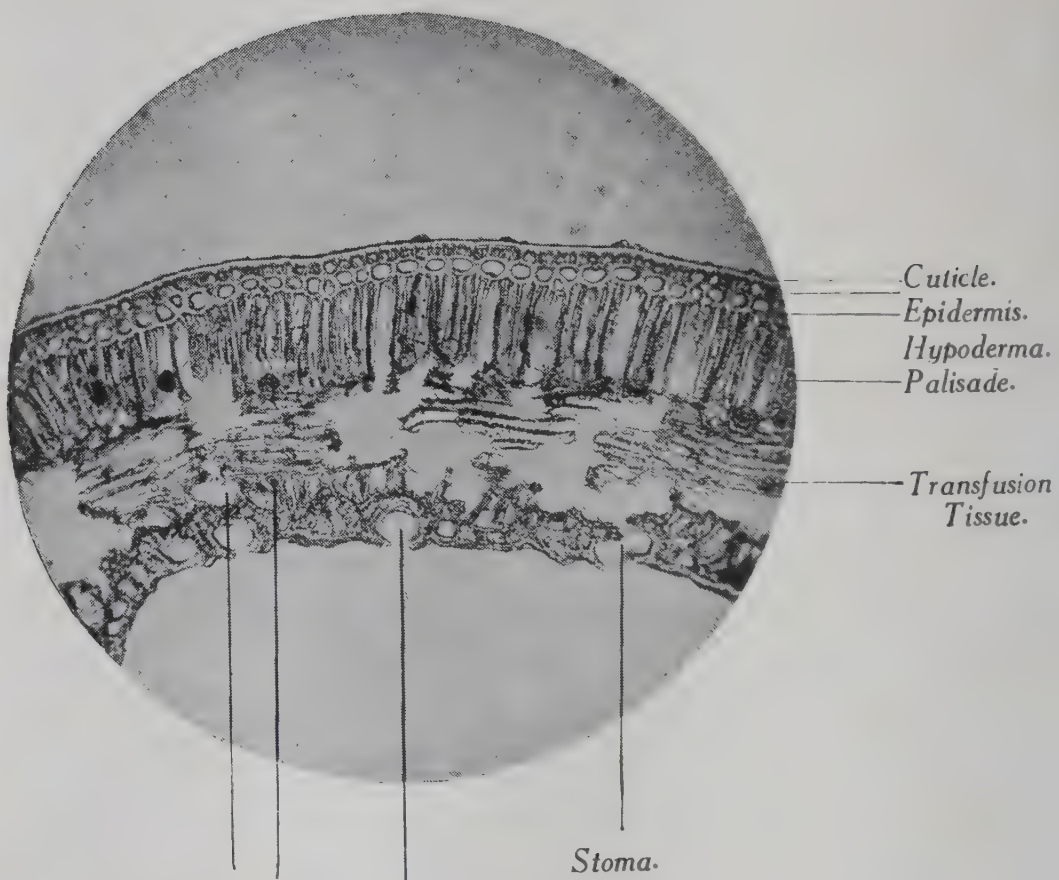

Fig. 79.

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and arranged at right angles to the surface, in close contact with one another like the planks of a palisade.

We next come on the spongy layer of the mesophyll in which the chloroplast-containing cells are irregular in shape and loosely arranged, only touching one another here and there, so that large intercellular spaces are left which communicate freely with the air through the stomata. Running transversely through the spongy mesophyll from the mid-rib towards the margin, is seen the *transfusion-tissue* composed of colourless cells, some empty, with dotted walls approaching in appearance and probably acting as tracheids, others containing granular protoplasm which are supposed to carry away the elaborated sap like sieve tissue. The absence of well developed vascular tissue, except in the mid-rib contrasts with the condition found in the leaves of Angiosperms in which the vessels usually ramify in the lamina almost up to the margin.

The lowest layer of the mesophyll approaches the palisade in character, but the cells are shorter, only two or three times as long as they are broad and irregularly arranged with large air-spaces between them into which the stomata open.

SPOROPHYLLS.

The megasporophylls or carpels, arise as whorls of modified leaves at the apex of the stem. At first they are closely pressed together to form a large yellow dome-shaped bud, surrounded at its base by brown linear scale leaves; but as the axis elongates the carpels become separated from one another and assume the horizontal position. The axis continues to grow and the following year produces a whorl of foliage leaves above the carpels. Fig. 76, reproduced from a photograph, shows this alternation of whorls of sporo-

phylls with foliage leaves. At the apex are seen the still vertical foliage leaves of this year, below a whorl of carpels, next the horizontal whorl of two-year-old foliage leaves, below which are seen hanging down the withered carpels of three seasons ago.

Each carpel bears from three to eight ovules or megasporangia, and is thick, succulent and yellow, in shape somewhat like the blade of a spear. The homology of the carpels with foliage leaves is shown not only by their alternation with the latter but also by an approach to the pinnate form at their apex. This is well seen in *Cycas revoluta*, the carpels of which produce round cord-like pinnæ at their apex. In *C. circinalis* (see Fig. 77) we find only a slightly dentate condition near the apex which turns green from the presence of chlorophyll, to indicate this homology.

Each ovule or megasporangium consists of a *nucellus* from the base of which, the *chalaza*, arises a thick *integument* that grows up to entirely surround the nucellus except at its apex, where it forms a small nipple-like projection perforated by an aperture, the *micropyle*. This leads down to a cavity, the *pollen chamber*, at the apex of the nucellus. The ovule is sessile, that is to say, it possesses no stalk. The portion of the carpel to which it is attached is called the *placenta*.

In the nucellus appears only one spore-mother-cell, which divides into four daughter-cells, only one of which becomes the *megaspore*. In the flowering plants this spore has unfortunately for such a long time been known as the *embryo-sac*, that it is difficult to avoid the name. The megaspore is not discharged from its parent plant but proceeds

Fig. 80.—Cycas circinalis, Cone of Male Tree.

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Fig. 82.
Stamen of C. circinalis.

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within the ovule to divide into a large number of cells and form the female gametophyte or prothallus. The *archegonia*, or female gonads, which produce the *ovum* or egg-cell, make their appearance in the upper part of the prothallus at the bottom of a hollow, which we may call the *sperm chamber*.

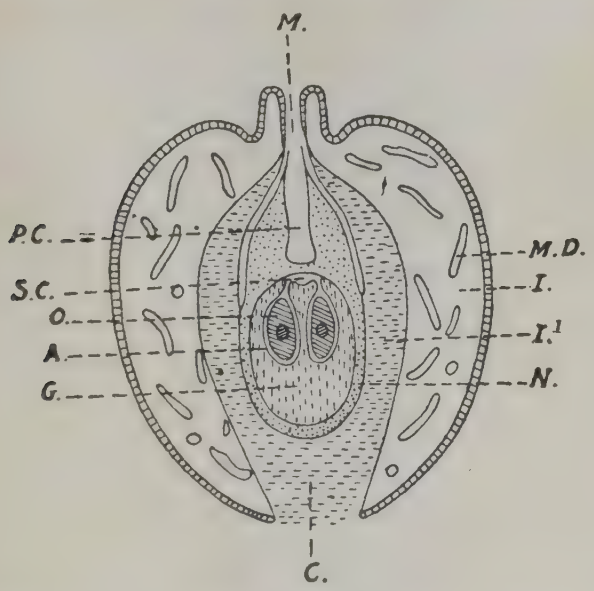

Fig. 81.—*Median longitudinal section of the megasporangium of C. circinalis showing the female gametophyte.*

A.—Archegonium.
C.—Chalaza.
G.—Female gametophyte.
I.—Integument outer portion.
*I*1.—Integument inner portion.
M.—Micropyle.
M. D.—Mucilage duct.
N.—Nucellus.
O.—Ovum.
P.C.—Pollen chamber.
S. C.—Sperm chamber.

The ovum of Cycas is about 2 mm. in diameter and contains a remarkably large nucleus, about 0.5 mm. in diameter, so large that when stained it is readily visible to the naked eye.

The male tree produces a terminal inflorescence in the form of a large cone from six to twelve inches high. The cone consists of a large number of woody scale-like leaves, the *microsporophylls*, arranged spirally on a central axis. This

axis is the true upward continuation of the stem. The subsequent growth in height of the tree is maintained by a lateral bud, which as it develops pushes aside the cone and grows vertically in the same direction as the trunk.

Each microsporophyll or *stamen*, bears on its under surface some hundreds of *microsporangia*. In these sporangia the spore-mother-cells divide into four pollen grains or *microspores*. In this division the number of the chromosomes is reduced so that each spore has only half as many as the mother-cell. In its earliest stage, the pollen is a true spore, consisting of a single cell enclosed in a two layered cell-wall. The outer layer, the exine is cutinised ; the inner, the intine, is of cellulose containing much pectin. When the pollen escapes from the sporangium we find it has already become a small prothallus, (male gametophyte) consisting of three or four cells. The first formed cells are called the vegetative cells ; from these later, is cut off the spermatogenous cell which again divides into two, one of which breaks up, the other is the sperm-mother-cell (Fig. 84).

The pollen grains are produced in vast numbers and are carried about by the wind. In this way some of them find their way to the ovules of the female tree. This method is extremely precarious and involves an enormous waste. Some years ago a female tree in Esplanade Road, Bombay, bore several seeds, although, as far as we are aware, the nearest male trees are in Victoria Gardens with about four miles of city streets intervening. Pollinisation takes place when the carpels begin to separate from one another. The pollen falls into the micropyle which is continuous with the

pollen chamber. In this is a quantity of mucilaginous fluid which slowly drying up, draws the pollen grains down to the bottom of the chamber. Here the exine ruptures; one of the prothallial cells grows out carrying with it a tubular process of the intine called the *pollen-tube*. The sperm-mother-cell enters the pollen-tube and there divides into two motile *spermatozoids* of a peg-top shape with a spiral band of cilia round their narrow ends (Figs. 85 and 86).

Fig. 83.

Fig. 84.

Fig. 85.

Fig. 86.

In the meantime the female gametophyte has increased in size, pushing aside the cells of the nucellus till the sperm

chamber with the archegonia at its base has come close to the bottom of the pollen chamber. The pollen-tubes bore their way through the intervening soft-celled tissue, and on reaching the sperm chamber rupture, allowing the spermatozoids to escape. The commotion caused by their spinning movement can be observed with a simple lens. They swim about actively in the fluid of the sperm chamber till they find the neck of the archegonium. Through this they pass and enter the ovum. The nuclei of the spermatozoid and of the ovum then unite to form the zygote nucleus.

To see the spermatozoids and pollen-tubes examine some pollinated ovules about the month of September. With the naked eye you can see the pollen tubes projecting from about 0·5 mm. to 1·5 mm. into the sperm chamber of the nucellus. As a rule from four to eight tubes may be seen, possibly as many as twenty, or as few as one. With a lens the united pair of spermatozoids may be recognised as an opaque white dot in the more pellucid tube.

Cut out this piece of nucellus and place it on a slide in some 8 per cent. solution of cane sugar. With the help of a dissecting microscope and a sharp knife cut off the ends of the tubes. Do not put on a cover glass, at least do not do so till you have examined with a 1 inch or $\frac{1}{2}$ inch objective, as you may crush the spermatozoids or restrain their movements.

If the spermatozoids are mature, they will soon begin to spin round and separate from one another. They usually keep up active movements for some hours. On an average the spermatozoids of *Cycas circinalis* are about 0·2 mm. in diameter.

The nucleus of the zygote divides successively into two, four, eight, sixteen, thirty-two, sixty-four, one hundred and twenty-eight and two hundred and fifty-six free daughter nuclei before their protoplasm separates and forms cell-walls. The embryo then becomes differentiated into an axis composed of a short radicle and a relatively large plumule with two large cotyledons. A large portion of the gametophyte remains as the *endosperm* of the seed. The integument of the ovule becomes the seed-coat with an outer succulent, and an inner hard layer. The ripe seed grows to the size of a small apple and from its size and the character of the seed-coats is popularly mistaken for a fruit of the drupe kind.

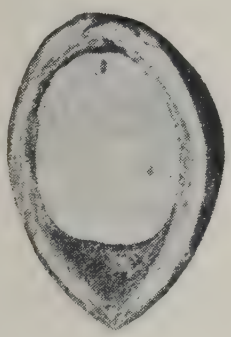

Fig. 87—SEED OF C. CIRCINALIS $\times \frac{1}{2}$.

FLOWERING PLANTS.

II.—ANGIOSPERMS.

The phylum of the Flowering Plants, better called the "Seed Plants," is divided into two great sub-phyla or divisions :—

(1) The naked-seeded plants or Gymnosperms, (Gr. *gymnos*, naked : *sperma*, seed) which bear their ovules exposed on open leaves. Cycas has already been studied as an example.

(2) The Angiosperms (Gr. *angeion*, a case or vessel) in which the ovules are enclosed in a case formed by the infolding of the sporophyll or leaf which bears them.

Take the pod of a Bean or Pea : split it along the border to which the seeds are attached and open it out flat. You will now readily see its homology with the sporophyll of Cycas. It is a spore-bearing leaf, folded longitudinally along its midrib to form a case enclosing the seeds, which, as in Cycas, are attached to the margin of the sporophyll. The common Fern which we have studied, bears only one kind of spore ; the gametophyte which arises from this spore is hermaphrodite, giving rise to both male and female gametes (spermatozoids and ova).

Some of the most highly developed plants of the Fern sub-kingdom, such as Azolla, often found floating in Indian tanks, and Selaginella, commonly cultivated in our fern-houses, bear two kinds of spores, small and large.

The smaller one, hence called the *microspore*, (Gr. *micros*, mall) gives rise to a small gametophyte (prothallus) which ears male gametes (spermatozoids) only. The larger, hence

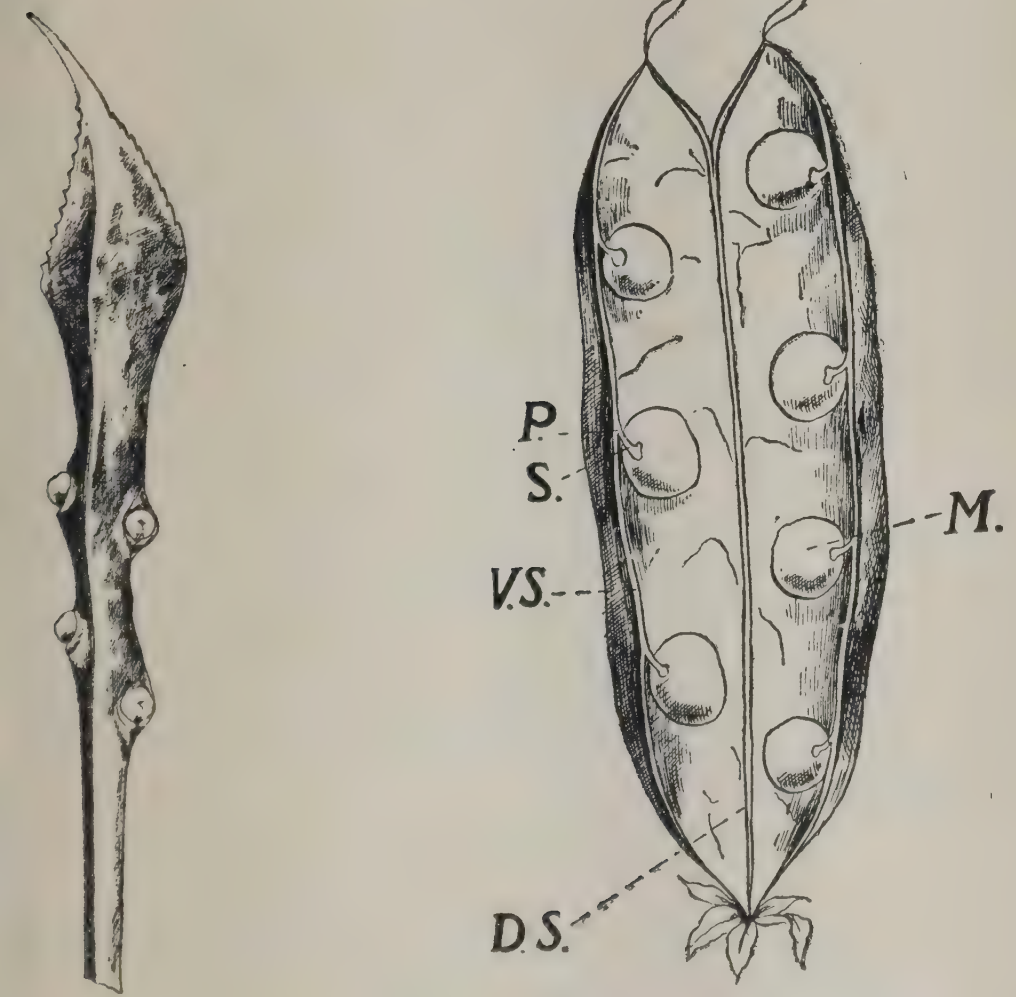

Fig. 88.—*Carpel of Cycas circinalis, a Gymnosperm.*
Fig. 89.—*Mature Carpel of Pea, an Angiosperm, opened along the ventral suture to show the attachment of the seeds to the margin of the carpellary leaf.*

D.S.—Dorsal suture (midrib of carpel).
M.—Megasporangium or ovule which has become the seed.
P.—Placenta.
S.—Stalk of the ovule.
V.S.—Ventral suture (margin of carpel).

called the *megaspore*, (Gr. *megas*, big) produces a gametophyte which bears female gametes (ova) only.

The Flowering Plants are descended from Fern-like ancestors and always bear two kinds of spore. The microspores, the homology of which has only recently been recognised, have for centuries been called *pollen-grains*.

Like the spores of the Fern, these separate from their parent plant, but they only give rise to their gametophyte when they fall on a special "soil" or situation. In the case of Cycas and other Gymnosperms, this is the micropyl of the ovule. In the case of the Angiosperms it is the stigma, a special tissue on the surface of the megasporophyll.

The true homology of the megaspore has only recently been recognised. The megaspore only leaves its parent plant after it has produced its gametophyte, and after the ovum has been fertilised by the sperm cell and an embryo (sporophyte) has been produced. These structures remain enclosed in the megasporangium, and the whole is then known as the *seed*, the most striking characteristic of the Flowering Plants.

THE FLOWER.

In the Fern the same leaf fulfils the functions of assimilation and of spore bearing. A division of labour accompanied by a differentiation of structure is characteristic of the higher animals and plants; so in the higher Flowering Plants we find the ordinary green foliage leaves solely devoted to the function of assimilation, while specially modified collections of leaves known as Flowers are adapted for the processes of reproduction.

A typical flower such as that of the Bean or Torenia consists of four whorls of modified leaves.

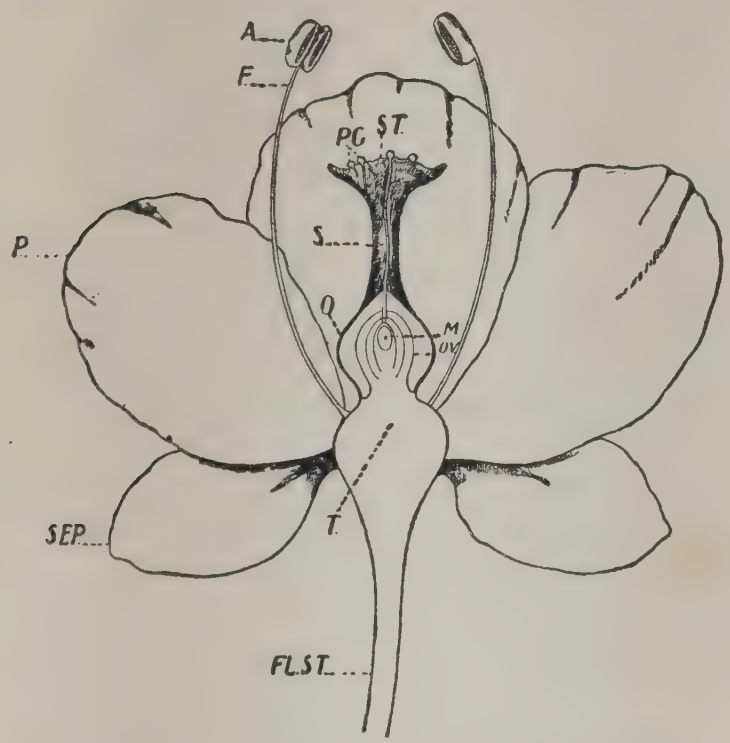

Fig. 90.—*Diagram of a typical flower.*

A.—Anther.
F.—Filament.
Fl. St.—Flower-stalk.
M.—Megaspore.
O.—Ovary.
Ov.—Ovule (Megasporangium.)
P.—Petal.
P.G.—Germinating pollen grains (Microspores)
S.—Style.
Sep.—Sepal.
St.—Stigma.
T.—Thalamus.

The point on a stem to which a leaf is attached is known as a *node*, the part of the stem between two successive leaves is known as an *internode* which is of varying length between successive foliage leaves; between the various whorls of a flower the internodes are so short that the nodes or origins of the floral leaves are all crowded together at the apex of

the flower-stalk to which the name *thalamus* (Gr. a marriage bed) has been given.

The outer two whorls are together known as the *perianth* (Gr. *peri*, around, *anthos*, flower). They are sometimes absent as they are not essential organs, but fulfil accessory functions of protection and attraction. If one whorl be absent, the flower is said to be *incomplete*; if both are absent the flower is *naked*.

The outermost whorl is composed of leaves called the *sepals*. They are most commonly green and unattractive for their principal function is to cover and protect the inner whorls while the flower is in the bud stage. From the fact that in most flowers the individual sepals are united together to form a little cup-shaped structure, the whole whorl is called the *Calyx* (Gr. cup).

The inner whorl of the perianth, the *corolla*, is composed usually of brightly coloured leaves, the *petals*, whose function is not only to protect the sporophylls but also to attract insects and other animals which may assist in carrying the microspores to and from other flowers.

The attraction of insects is of the utmost importance in the cross-pollination of many flowers. The flower attracts not only by brilliance of colour which is most striking in countries where bright sunshine is the rule. In colder climates, where for weeks at a time the sky is overcast, sweet-smelling flowers predominate.

Nectaries or honey-glands, which secrete a sugary solution, are common in the deeper portions of many bell-shaped and tubular flowers, for example, on the disc of Torenia. To sip the honey the insect must thrust his head or proboscis

deep into the tube of the corolla. In doing so the pollen is brushed off and adheres to the body of the insect, who then unconsciously carries it to another flower and deposits it on its stigma.

Insects may be attracted by sight, smell or taste or by a combination of any of these senses.

One of the most marvellous adaptations to ensure cross fertilisation is found in *Aristolochia fetida*. The huge trumpet-shaped perianth gradually narrows, but again expands at its lower end into a hollow globe in which we find the stigma and stamens. The stigma ripens much earlier than the stamens.

The inner surface of the perianth is of a streaky red color closely resembling a piece of lean meat. The plant receives its name *A. fetida*, from the stench, like that of decomposing flesh, given off by the perianth. The Green Bottle Fly, familiar in the dissecting-room and in the butcher's shop, where it feeds on the juices of decaying flesh, is so completely deluded by the smell and appearance of the flower that he enters the bulb seeking for rotten meat !

The narrow, tubular portion of the perianth before it enters the bulb, is lined with stiff hairs, their sharp points all directed inward. The fly, pushing these hairs aside, enters the bulb. If he is carrying pollen, this is deposited on the stigma. Until the pollen is ripe the stigma lobes are folded down and cover the anthers. When the disappointed fly tries to escape he cannot do so for the points of the bristles face him like minute spears. Later, when the stigma is pollinated, its lobes rise up and expose the ripe anthers, allowing the imprisoned flies to take up a fresh load of pollen.

By this time the perianth has begun to wither, the bristles losing their turgidity, become flaccid and soft.

The hungry flies now escape, and none the wiser for their experience, enter another flower in search of food, undergo a second term of imprisonment and incidentally pollinate the flower. So complete is the deception that we have found over a hundred flies entrapped in a single flower.

The student should notice that in many cases particular species of insect frequent almost exclusively one definite species of flower. They do so to such an extent that, long before the value of their services in cross-pollination was recognised, a large number of butterflies and moths were given as specific names, those of the flowers they particularly haunt.

Vanilla, a species of Orchid, native of Mexico, has been imported into the Seychelles where its cultivation is an important industry. Unfortunately the insect which, in Mexico, gratuitously pollinated the flowers was not imported along with the plant. Hence coolies have to be employed to pollinate each individual flower before it gives fruit.

THE SPORE LEAVES.

The inner two whorls are the essential organs, the *sporophylls*, leaves whose function is to bear spores. The student has no difficulty in recognising the sepals and petals as modified leaves, but the structure of the sporophylls is so modified that their homology with leaves is not so readily recognised. This modification chiefly consists in a folding-in of the leaf to form a case which encloses the *sporangia*.

The sporophylls of the outer whorl (sometimes there are several whorls as in Water Lily, Wild Rose, *Champa*, *Mhendi*) are known as stamens and are so modified that there is little resemblance to an ordinary leaf. Each stamen consists of a slender stalk, the *filament*, bearing a two-lobed *anther*. Each anther-lobe consists of two *microsporangia* or pollen-sacs in which the *microspores* (pollen grains) are formed.

The homology of the stamens with leaves is well shown in the Lotus, *Padma*, where we find a gradual transition from petal to stamen in successive whorls; also in many plants (such as the Rose) which in the wild state have a single whorl of five petals and numerous stamens, but in cultivation *appear* to have numerous petals and few or no stamens owing to the fact that the stamens have become barren and grown petal-like.

The inner whorl known as the *pistil* or *gynæcium* (Gr. *gyne*, female; *oikos*, house) is composed of a number of leaves called *carpels*, which whether single as in the Bean, two as in Torenia or several as in the Bhendi, form in their lower part one or more chambers, collectively called the "ovary"* in which the megasporangia (ovules) are enclosed. On the top of the carpel is a moist, sticky surface, the *stigma*, specially adapted for the reception and germination of the microspores.

The stigma is usually separated from the ovary by a stalk or neck, the *style*. The part of the ovary to which the

---

* A very unfortunate name as it has no homology with the ovary, *i.e.*, the female gonad of animals.

ovules are attached is known as the *placenta* and is generall homologous with the margin of the carpellary leaf.

The ovule may be attached to the placenta by a shor stalk, the *funicle* (Lat. *funiculus*, a little rope) or may b *sessile* as in Cycas. Each ovule consists of an inner portion the *nucellus* (Lat. a kernel) completely enclosed by one o two coats, except at its apex, where a small aperture, th micropyle, is left. Where the nucellus and the coats unit is called the *chalaza* (Gr. a pimple).

In the nucellus we find only one spore, the *megaspore* a very large cell enclosed in a cellulose wall.

It is a characteristic of the Flowering Plants that the megaspore never becomes free but develops into a gameto- phyte in the interior of the sporangium (ovule).

We have seen in the Gymnosperm, Cycas, that the female gametophyte, though relatively smaller than the herma- phrodite gametophyte of the Fern, is still large enough to be readily seen with the naked eye, is composed of some hundreds of cells and may bear several archegonia.

In the Angiosperms the female gametophyte is greatly reduced and, at the time the gamete is formed does not consist of more than seven or eight cells, including the gamete or *ovum* and perhaps an archegonium of two cells.

The Megaspore and the Female Gametophyte.

Take a newly opened flower of Torenia : open the ovary and remove the minute ovules with needles, using the dis- secting microscope. Examine in water or preferably in

3 per cent. solution of sugar, some of the ovules with the low power of the microscope.

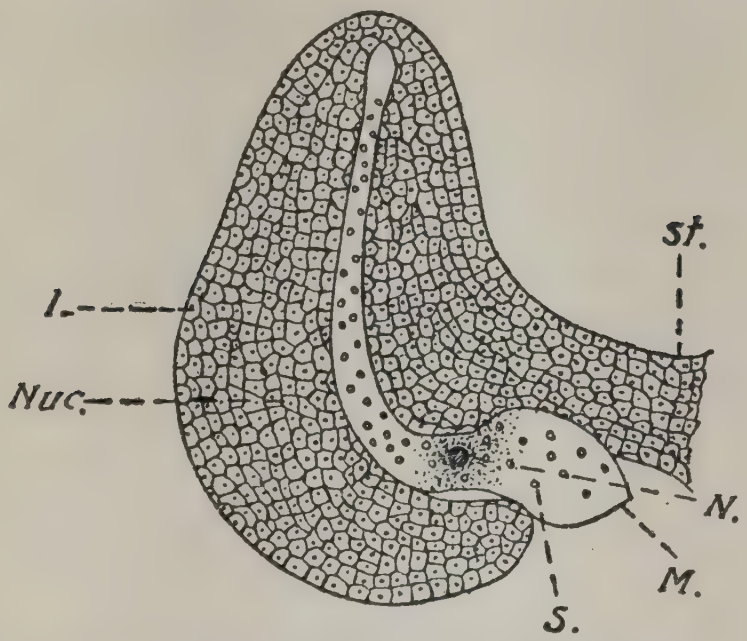

Fig. 91.—*Megasporangium of Torenia showing the megaspore.*

I.—Integument.
M.—Megaspore.
N.—Nucleus of megaspore.
Nuc.—Nucellus.
S.—Starch grains.
St.—Stalk of megasporangium.

Note that the ovule is inverted so that the micropyle is close to the broken stalk. The ovule has only one coat which fortunately is transparent and allows us to see the inner structures. In the young ovule we find a very large cell protruding from the micropyle; this is the megaspore which in most plants is embedded so deep in the nucellus that it can only be seen on dissection. We select Torenia because observation is very easily made in this plant. The minute transparent ovules of many Orchids and of Gloxinia are also favourable objects for observing the megaspore which is in these plants in its normal central situation.

The portion of the megaspore protruding from the

micropyle is readily seen. With care you will see that the whole cell is flask-shaped, the neck portion being embedded in the centre of the nucellus in the normal situation of the megaspore in most plants.

Observe the large vacuole in the protruding part of the megaspore. Note that in most megaspores there is a large number of starch granules which are absent from the other cells of the nucellus. If you have difficulty in recognising the deeper portion of the spore, you can take advantage of this fact. Run in a drop of iodine solution under the cover-

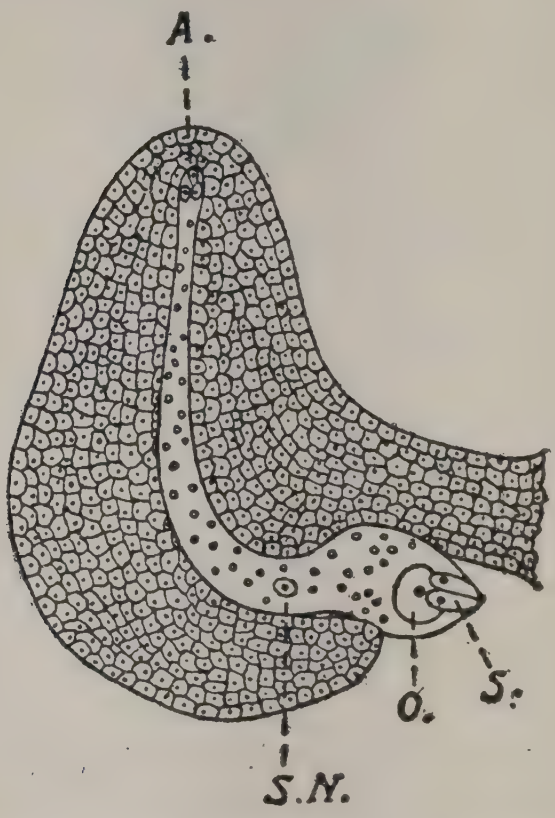

Fig. 92.—*Megasporangium of Torenia after the formation of the female gametophyte.*

A.—Antipodal cells.
O.—Ovum.
S.—Assistant cells.
S. N.—Secondary nucleus.

glass. The deeper portion of the megaspore is now made obvious by the staining of the starch granules.

In a slightly older ovule we find the nucleus of the megaspore has divided successively into two, four and eight nuclei each surrounded by cytoplasm but no cell-wall. In this way a small gametophyte has been produced inside the cell-wall of the original megaspore.

Three of these cells take up a position furthest from the micropyle. These are called the "antipodal cells;" their function is unknown and we will not discuss them further.

Three of the other cells come to the pole nearest the micropyle—in Torenia projecting outside it. We may regard these as the homologue of the archegonium. The most central of the three is the female gamete or ovum. The other two are known as the "assistant cells."

Before these cells have taken up their position the remaining two nuclei usually unite together near the centre of the megaspore, so that ultimately the gametophyte is composed of seven naked cells all enclosed in the original cell-wall of the megaspore.

The Microspore and the Male Gametophyte.

The microspores (pollen-grains) when ripe are set free by the bursting of the sporangia. They are dependent on "chance" agencies for their transport to the stigma. Some, such as those of Maize and Cycas which depend on the wind for their dispersal, are light and dry. Those which are carried by insects are sticky with a viscid secretion and in many species bear minute projections or spines which enable them to adhere to the bodies of insects. Like all spores the pollen-grain at first consists of a single cell. Its protoplasm is en-

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closed in a double cell-wall. The outer coat, the *extine*, is firm and cutinised ; the inner, the *intine*, is softer and formed of varying amounts of cellulose and pectin.

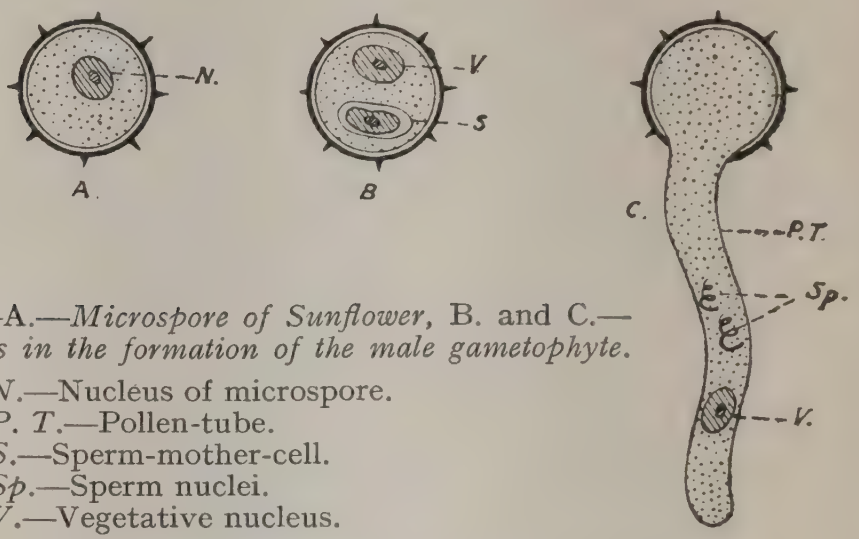

Fig. 93.—A.—*Microspore of Sunflower*, B. and C.—*Stages in the formation of the male gametophyte.*

N.—Nucleus of microspore.
P. T.—Pollen-tube.
S.—Sperm-mother-cell.
Sp.—Sperm nuclei.
V.—Vegetative nucleus.

When the pollen falls on the stigma its nucleus has already divided into two daughter-nuclei. On germination the outer cell-wall gives way, and the inner wall with the contained cytoplasm protrudes as the pollen-tube. The two daughter-nuclei also enter the pollen-tube. One of these, the gamete-mother-nucleus, divides again to form two male gametes or sperm nuclei ; the other, the vegetative nucleus, takes no part in reproduction.

Each nucleus with the cytoplasm surrounding it constitutes a naked cell ; no dividing cell-wall is formed, but all are enclosed in the prolongation of the inner cell-wall of the parent spore.

The pollen-tube with the contained nuclei is the male gametophyte of Flowering Plants. It is a minute structure only visible under the microscope.

Take a cover-glass and place two or three drops of an 8-10 per cent. *solution of cane sugar on it. Into this syrup shake a few pollen-grains—microspores—of Torenia. Invert the cover-glass over a hollowed slide and leave aside in the dark for two or three hours. Then examine first with the low power of your microscope, later with the higher power. You will find some of the microspores have sprouted. The nucleus has divided into two ; the outer coat of the microspore has given way and the inner coat with its contained protoplasm has grown out as a long tube, the microscopic representative of the male gametophyte. Under favourable conditions the growth is so rapid that you can see the tube elongating as you watch.

To see the pollen-tubes of Sunflower take pollen that has been shed for several hours. The syrup may vary from 5 to 30 per cent. Growth is much slower than in Torenia, and is seldom seen in less than twelve hours.

The germination of the microspore has thus resulted in the formation of a small gametophyte or prothallus composed of only three cells, two of them being the male gametes.

We have seen that the male gametes of the Fern were set free as actively swimming spermatozoids, which, like the spermatozoa of Hydra, by their own movement found their way to the ovum. In Cycas we see they are still actively moving spermatozoids, provided with motile cilia but they are only developed after the microspore has been carried by the wind into the ovule.

In the highest Flowering Plants, the Angiosperms, the male gametes have lost all cilia or flagella and almost all

* About 40 grains in an ounce of water.

power of locomotion. The plant has to rely on chance external agencies, such as insects and currents of wind and water to carry the microspores to the stigma. In most flowers the male gametes have nothing in their appearance or structure to remind us that they are gametes, but their conjugation with the ovum proves their homology.

The male gametes of the higher animals and plants are always cells in which the proportion of nuclear substance greatly preponderates over the cytoplasm.

In some pollen-tubes of Sunflower stained by us with Iron hæmatin the gamete nuclei show a striking resemblance to the spermatozoids of Ferns. All are twisted, and many are of a cork-screw type with as many as five turns. This staining process is too complicated for the elementary student. See Fig. 94.

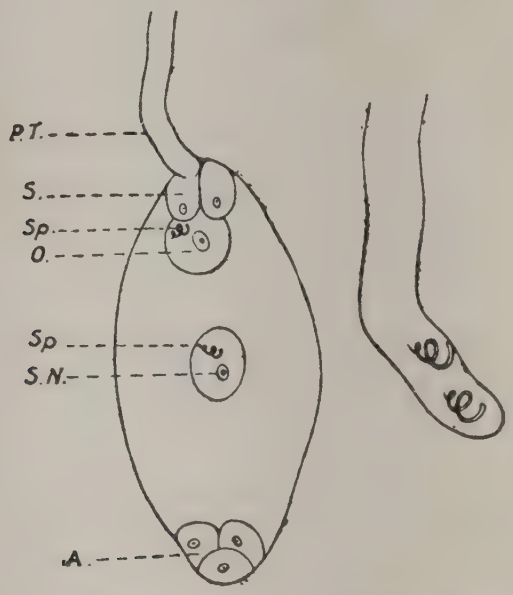

Fig. 94.—*Diagram of the female gametophyte of Sunflower at the time of fertilisation. On the right the pollen-tube containing the sperm nuclei is shown enlarged.*

A.—Antipodal cells.
O.—Ovum.
P. T.—Pollen-tube.
S.—Assistant cells.
S.N.—Secondary nucleus.
Sp.—Sperm nuclei.

FERTILISATION.

The pollen-tube penetrates the stigma, traverses the style, enters the micropyle and reaches the assistant cells. The cell-wall of the original megaspore having given way, the tube works its way between or through the assistants till it comes in touch with the ovum. The wall of the tube now gives way, one of the sperm cells—male gametes—escapes and its nucleus conjugates with that of the ovum. Thus fertilisation is completed and the zygote is formed.

The process of fertilisation is readily seen in Torenia. It may be seen in flowers 24 to 48 hours after the stigma lobes have shut, but a more certain method is to pollinate the flowers by hand. Cut out the stamens of newly-opened flowers. Tie small paper or cloth bags over the flowers to prevent chance pollination. When the stigmas are open place some pollen from ripe stamens on their surface in the evening. On the second morning with the help of a dissecting microscope carefully remove the ovules from the placenta with as much and as many of the pollen-tubes as you can. Examine in 3% sugar solution. Stain other specimens with iodine or safranine.

THE EMBRYO SPOROPHYTE AND THE SEED.

The zygote which has resulted from the conjugation of the gametes—sperm cell and ovum—soon divides into a number of cells and develops into an embryo sporophyte. The coats of the ovule thicken and harden becoming the seed coats.

It has already been mentioned that three of the cells of the female gametophyte became the ovum and the assistant cells, three became the "antipodal cells," while the remaining two nuclei united to form the "secondary nucleus."

In many plants the second sperm cell has been seen to leave the pollen-tube and conjugate with this secondary nucleus. In many plants it certainly does not do so, but whether it does or not, the " secondary " nucleus repeatedly divides to form a number of cells,—at first naked—but subsequently furnished with a cell-wall. The tissue so formed, known as the *endosperm* (Gr. *endo*, inside : *sperma* the seed) contains much reserve food-material such as oil and starch for the nourishment of the embryo.

These structures, the embryo, the endosperm and the altered coats of the ovule constitute the *seed*.

In some plants such as Cardamom, *Haldi* and Ginger, a portion of the nucellus which is then called the *perisperm* (Gr. *peri*, around ; *sperma*, the seed) persists around the endosperm (Fig. 95). In many seeds such as Sunflower, Pea, Bean, *Dal*, the whole of the endosperm is consumed by the embryo at an early stage. In such cases the cotyledons themselves hold the reserve food material.

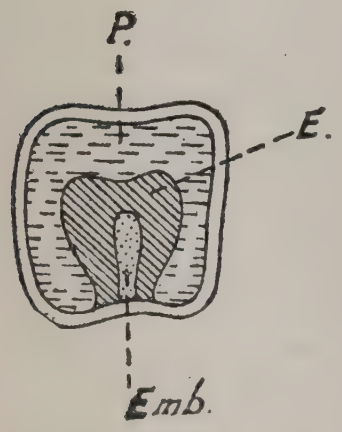

Fig. 95.—*Longitudinal section of a Cardamom Seed.*
E.—Endosperm. *Emb.*—Embryo sporophyte. *P.*—Perisperm.

In the ripe seed further development is capable of being suspended for an indefinite period. When planted in a suitable soil at a suitable season, the resumption of development is spoken of as *germination*.

We have seen that fertilisation in the angiosperm not only results in the formation of an embryo but causes changes

in the tissues of the ovule which result in the formation of the seed.

Changes also result in the structure of the carpel invariably and sometimes in other structures in its neighbourhood, such as the perianth or the thalamus. These altered structures are collectively known as the *pericarp* (Gr. *peri*, around ; *carpos*, seed). The pericarp which may become leathery, stony or succulent, with its enclosed seeds is known as the *fruit*.

We have now seen that there is a regular alternation of a sexual with an asexual generation in the Flowering Plant.

We have also seen how in the course of evolution the gametophyte stage of the plant steadily diminishes while the sporophyte stage becomes more and more conspicuous. The gametophyte which is the conspicuous generation in the Algae and Fungi like Spirogyra and Mucor, has become small in the Ferns but still leads an independent existence.

In the Gymnosperm Cycas, the female gametophyte still consists of some hundreds of cells, and may bear several archegonia, though it never leaves the interior of the sporangium.

In the Angiosperms it is generally microscopic in size consisting of only seven cells ; it never leads an independent existence but throughout its life remains dependent on, and enclosed within the megasporangium (ovule) of its parent sporophyte. The process of evolution has been gradual, continuous and unmistakable. In both gymnosperm and angiosperm the male gametophyte always consists of still fewer cells.

The Flowering Plant as seen by us in the field is the sporophyte generation bearing two kinds of spores. The gametophyte has to be found by dissection and the microscope in the laboratory.

THE SEED.

We have seen that the seed may consist of—

1. The young embryo.
2. The altered coats of the megasporangium. In addition there is often a tissue,—
3. The endosperm, developed from the secondary nucleus of the megaspore.
4. Rarely not only are the coats of the ovule present but also part of the nucellus may remain which is then called the perisperm.

In the Bean and Sunflower all the endosperm has been consumed and its reserve food-material stored up in the embryo, especially in the cotyledons. Such seeds which when ripe contain neither perisperm nor endosperm are said to be *exalbuminous*.

Seeds like those of Torenia and Maize in which when ripe a quantity of endosperm persists, as well as those few seeds like Canna in which some perisperm persists, are spoken of as *albuminous*. Soak in water for twelve to twenty-four hours some of the seeds of the Bean, Torenia, Cardamom and Castor Oil plant, also some grains of Maize and fruits of Sunflower.

Wipe dry a soaked Bean seed. Note that the seed-coat is smooth all over except at a small rough spot on its concave margin. This spot, called the *hilum*, is the scar left by de-

taching the seed stalk. Squeeze the seed gently between your finger and thumb. You will see a minute drop of fluid exude from a small hole close to the hilum. This hole is the *micropyle* (Gr. *mikros*, small : *pylon*, entrance) through which the embryo root will make its way.

Peel off the seed-coat and you will find the remaining portion of the Bean seed consists solely of the young embryo. During the ripening of the seed the embryo has absorbed all the endosperm, all the remains of the nucellus and even the inner, softer coat of the ovule.

On examining the embryo you find it consists of—

(*a*) Two thick fleshy seed-leaves or *cotyledons*. Separate these at the edge furthest from the hilum preserving this latter as a hinge, and you find

(*b*) the *axis* composed of—

(1) the *radicle* or rudimentary root which, on germinating, bores its way through the micropyle ;

(2) the *plumule* or rudimentary shoot, at the apex of which a rudimentary leaf-bud can be recognised with the help of a lens.

The fruit of the Sunflower is popularly mistaken for the "seed." It consists of a single seed enclosed in a pericarp derived, not only from the ovary but also from the rudimentary calyx which closely invests the ovary.

Remove the pericarp and you find the seed is of the same exalbuminous character as the Bean. The endosperm is all absorbed and we find a thin seed-coat enclosing an embryo

with two cotyledons, the radicle at the base of the fruit and a very small plumule enclosed between the cotyledons.

In the case of most Beans the cotyledons remain permanently underground after the seed has germinated. In the Goar Bean and in Sunflower the growing axis carries them above ground when they take on the green colour characteristic of foliage leaves.

The seeds of Torenia are albuminous, a considerable amount of endosperm being present in the ripe seed. As they are so small, the large seed of the Castor Oil plant will be studied instead.

Strip off the brittle, polished and spotted *outer seed-coat* and you will find a thin *inner seed-coat* enclosing an oily tissue, the endosperm. Cut longitudinally through this endosperm which surrounds the embryo and you will find a central lens-shaped cavity on the walls of which are the two flat cotyledons with the small plumule between them and the radicle close to the hilum.

Make a longitudinal section through a Cardamom seed. Inside the seed-coats you observe a white tissue, the *perisperm*, surrounding a greyish, oily *endosperm* which in turn surrounds a straight *embryo* with a single cotyledon. (Fig. 95.)

Examine the soaked grains of Maize or some soft grains that are barely ripe. The student is at first liable to mistake the grain of Maize for a naked seed, but an examination at an earlier stage will show the long style and thus indicate that the grain is really a one-seeded fruit in which the pericarp, consisting of the wall of the ovary, is firmly attached to the seed-coat throughout its whole extent.*

* Such a fruit is called a *Caryopsis*.

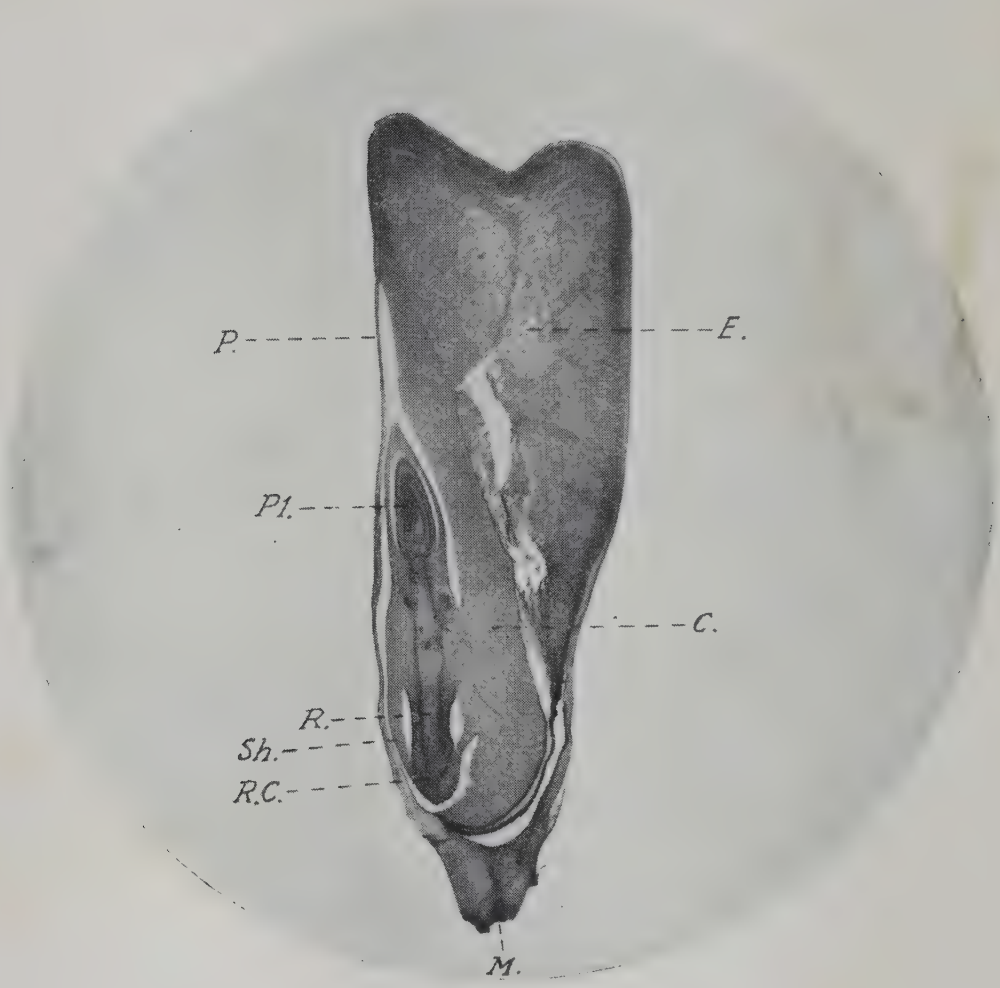

Fig. 96.—*Longitudinal section of the fruit of Maize.*

C.—Cotyledon.
E.—Endosperm.
M.—Micropyle.
P.—Pericarp.
Pl.—Plumule.
R.—Radicle.
R. C.—Root-Cap.
Sh.—Sheath.

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In some of the fruits a slight projection or scar remains to mark the site of the style. Without dissection the embryo can be seen as a paler streak in the yellow endosperm.

Make a vertical section through the centre of the embryo and examine the cut surface with a lens. You can recognise on the outside (Fig. 96.)

(1) the pericarp firmly adherent to ;

(2) the seed-coat, without any intervening space unlike most fruits ;

(3) the endosperm, a large yellow mass forming the greater part of the seed ;

(4) the embryo in the situation already recognised. The radicle of the embryo enclosed in a *root sheath* points toward the hilum : the plumule surrounded by its sheath forms the opposite end of the axis nearest the scar of the style.

Separating the axis from the endosperm is a shield-like structure, the *scutellum* (Lat. a little shield) which we may regard as the single cotyledon. Its function is to absorb the food material from the endosperm for the benefit of the embryo. In an old seed you will note that the ferment of the scutellum has acted on the part of the endosperm near it and rendered it white and floury.

THE STEM.

By the axis of the plant we indicate the root and shoot taken together. The term shoot includes the stem and its lateral organs, the leaves, in other words all those structures which develop from the plumule.

The stem usually grows upward toward the light to which it exposes the leaves, but in some cases such as the Male

Fern, Potato, Ginger, Canna, etc., we find underground stems. Such underground stems can be distinguished from roost by the fact that they bear leaves or by the presence of scars indicating the situation of fallen leaves.

In the Bean the stem is weak, climbing from the ground by twisting round any support that it can find.

The stem of Sunflower is erect, cylindrical and terminated at its apex by an inflorescence of numerous small flowers. At intervals it bears leaves inserted at the nodes. At the base of the young stem the leaves are *opposite*, that is to say two leaves are borne opposite one another at the same node. Higher up, where only one leaf is attached to each node, the arrangement is said to be *alternate*.

Examine carefully and find the two nearest leaves that are in the same vertical line with one another. You will find each fifth leaf is in the same vertical line. Take a piece of string, hold one end at the insertion of a leaf, pass the string on to the next leaf above it and on successively from leaf to leaf, till the string arrives at the base of a leaf vertically above the one from which you started. In Sunflower each 5th leaf is in the same vertical line. The string has passed 2 times round the stem in this manœuvre, so it is obvious the *angle of divergence* between any two successive leaves is $\frac{2}{5}$th the circumference of the stem.

You will find there is a definite angle for each plant, so that though the leaves appear *scattered* promiscuously, there is really a definite law for the *leaf-arrangement* of each plant. It is usual to indicate the leaf arrangement by the fraction representing the angle of divergence. As the branches arise in the axils of the leaves the leaf arrange-

ment greatly influences the *habit* or general appearance of the plant.

The most common angles of divergence are :—

$$\frac{1}{2}, \frac{1}{3}, \frac{2}{5}, \frac{3}{8}, \frac{5}{12}, \frac{8}{21}.$$

These divergences can easily be remembered as you can see that each numerator and each denominator is the sum of the two next preceding it.

The stem of Torenia is four-sided, square on section. Shortly after leaving the ground it gives off a number of nearly equal branches, there being no upward continuation of the main stem.

The stem of Maize is erect, cylindrical and herbaceous. Its greater portion is hidden by the ensheathing bases of the leaves. Most plants of the Grass family have a characteristic hollow stem, but Maize and Sugar-cane are exceptions having solid stems. The leaves arise in two ranks from the nodes which are well-marked as ringed swellings between the internodes. Their angle of divergence is therefore $\frac{1}{2}$.

Bean, Sunflower, Torenia and Maize are all *herbs*, by which term we mean plants with succulent, herbaceous stems, which never become covered externally with a brown corky layer of bark and which do not internally form a large quantity of wood. They remain green throughout their life. Those that die down each year, after they have borne their fruit, are called *annuals*.

In many herbs only the upper portions die down at the end of the year. They renew their life each monsoon by means of underground stems or roots. Such herbs are called *perennials*.

Trees and shrubs possess woody persistent stems or *trunks* and bear fruit for many seasons. There is no definite distinction beyond size between the tree and the shrub. The latter is smaller and usually retains its lower branches so as to appear *bushy* in habit. Trees are usually erect; as they grow in height they often lose their lower branches or the lower inter-nodes elongate, so that the main stem becomes a *trunk*.

THE LEAF.

A typical leaf consists of three parts—

(1) The proximal *leaf-base* by which it is attached to the stem.

(2) The distal lamina or *leaf-blade* which is usually flattened so that a large surface may be exposed to the sunlight.

(3) Between the blade and the leaf-base there is often a *leaf-stalk* or petiole.

On the shape and other modifications of these various parts the character of the leaf depends.

For instance in Maize we find—

(1) The leaf-base broad and ensheathing the circumference of the stem. The sheathing base is split in front.

(2) The blade is long and strap-shaped, the *apex* pointed. There are no teeth, indentations or notches on its margin, so the margin is said to be *entire*.

(3) There is no leaf-stalk, so the leaf is said to be *sessile*. Where the leaf-base unites with the blade is a little membrane or fringe called the

ligule. It is very generally present in the Grasses and serves to divert water trickling down the blade from making its way between the stem and the sheathing leaf-base. The veins run parallel with one another.

In the seedling of Sunflower we notice that at the base of the stem two leaves are inserted *opposite* one another at each node. Higher up they arise singly from the nodes in *alternate* fashion. The leaf-blade is large, its surface hairy, its outline is somewhat *ovate* with the apex pointed; its margin varies in different varieties. In some it is entire, in others it is marked by shallow notches forming blunt teeth all pointing toward the apex like the teeth of a saw; in this case the margin is said to be *serrate*. The leaf-base embraces part of the circumference of the node. Between the base and the blade is a leaf-stalk deeply grooved on its upper surface. The veins are not parallel as in Maize, but form a coarse network better seen on the under (dorsal) than on the upper surface. The angle which the upper surface of a leaf makes with the upper part of the stem is called the axil (Lat. *axilla*, the armpit). All normal branches arise as buds in the axil of a leaf.

In Torenia the leaves arise in pairs opposite one another but it will be seen that each pair is at right angles to the pairs immediately above and below. This is called the *decussate* leaf-arrangement. (Lat. *decussatus*, arranged cross-wise like X.)

Each leaf is ovate, its apex pointed, its margins serrate, its surface smooth, though minute hairs can be seen with the microscope.

No matter how deeply the margins of a leaf are indented or incised, a leaf is called *simple* so long as the incisions or indentations do not actually reach the leaf-stalk or midrib. If, as in Cycas, Male Fern, or Bean they actually reach the rachis, the leaf is said to be *compound* and each division is called a *leaflet.*

The leaf of the Bean is compound and its character varies in the different genera and species. In Goar Bean and in *Phaseolus multiflorus* there are three leaflets attached to a common leaf-stalk. In *Vicia faba* there are four to six leaflets. At the leaf-base you find two small lance-shaped, leaf-like *stipules.*

The student often finds a difficulty in distinguishing a leaf from a leaflet. It will help him to remember that buds or branches usually arise in the axil of a leaf, never in the axil of a leaflet.

THE ROOT.

The root is that part of the axis which as a rule grows downward and whose functions are—

(1) to fix the plant to the earth and

(2) to absorb water and soluble food-material from the soil.

Roots never bear leaves ; their apex is covered by a root-cap, contrasting with the naked growing-point of the stem.

By the *primary* root we mean the direct downward prolongation of the embryonic radicle. In many plants such as Cycas, Sunflower, Bean, Torenia and Radish, the primary root is distinctly thicker than any of its branches and is then

spoken of as a *tap-root.* Any branches which the primary root may give off are spoken of as *lateral* or *secondary* roots.

All roots that are derived from the radicle or its branches are spoken of as *true* roots. Should roots arise from the stem or, as they do extremely rarely, from a leaf, they are called *adventitious* roots.

In Maize and Monocotyledons generally, the primary root is not more developed than its branches. It may die off soon after germination as in Maize, and its functions usurped by its branches, the secondary roots, and the adventitious roots given off from the lower ernodes of int the stem just above the first few nodes.

Good examples of adventitious roots arise from the lower internodes of the stem of Maize, and most Monocotyledons. They are familiar as aerial roots in the Banyan, Pipal and Screw Pine. They can be artificially produced by placing a cutting of Croton or the cut end of a leaf-stalk of Begonia in a vase of water.

Anatomically roots are distinguished from stems—

(1) in that they bear no lateral organs except branch roots, similar in structure and function to the main root. In contrast, stems bear as lateral organs leaves which differ in structure and function from the stem itself.

(2) The growing point of the root is not naked but covered by a root-cap. The other characteristics of the root will be dealt with in the chapter on histology.

Monocotyledons and Dicotyledons.

The Angiosperms are divided into two great *classes*—the Monocotyledons (Gr. *mono*, single) and the Dicotyledons (Gr. *di*, two) so called because one of their main distinguishing features is that their seeds have one and two cotyledons respectively.

The presence of a cambium layer between the wood and the phloem of the vascular bundles in the Dicotyledons, enabling their stems to increase in thickness by the growth of fresh wood and bast, and the absence of a cambium layer in the Monocotyledons is another characteristic.

In Dicotyledons the radicle is generally continued as a primary or tap-root. In Monocotyledons the radicle does not develop into a main root but breaks up into a number of nearly equal secondary roots. Adventitious roots are often given off by the lower part of the stem.

The leaves in many Monocotyledons have parallel veins. In Dicotyledons the veins generally form an obvious net-work.

In Monocotyledons the calyx and corolla are seldom of different colours. The number of floral leaves in a whorl is generally three. In the Dicotyledons the number of leaves in a floral whorl is more often four or five, but there are numerous exceptions.

We take Maize as an example of the Monocotyledons. It belongs to the Natural Order of the Grasses which includes the Bamboo, Sugar-cane, Wheat, Rice and Millet as well as the common fodder grasses. Torenia, Sunflower and Bean are types of the Dicotyledons.

INFLORESCENCE OF MAIZE.

The stem is terminated by the branched male inflorescence. The female inflorescence covered by numerous large bracts arises laterally, low down on the stem.

The flowers of Maize owing to the suppression of the perianth are by no means typical of the Monocotyledons. They are unisexual but in other respects are a fair example of the Grasses.

" Male " and " female," more accurately termed *staminate* and *pistillate*, inflorescences are borne on the same plant. The male inflorescence is terminal on the stem and branched. Its secondary branches bear a number of small bud-like bodies on short stalks. Each of these is a secondary inflorescence called a *spikelet*, containing two staminate flowers enclosed in two scaly bracts technically called the *outer glumes*. Remove these and you find two pairs of white bracts, each pair enclosing a staminate flower. The outer bract of each pair is called the *flowering glume*, the inner, the *pale*.

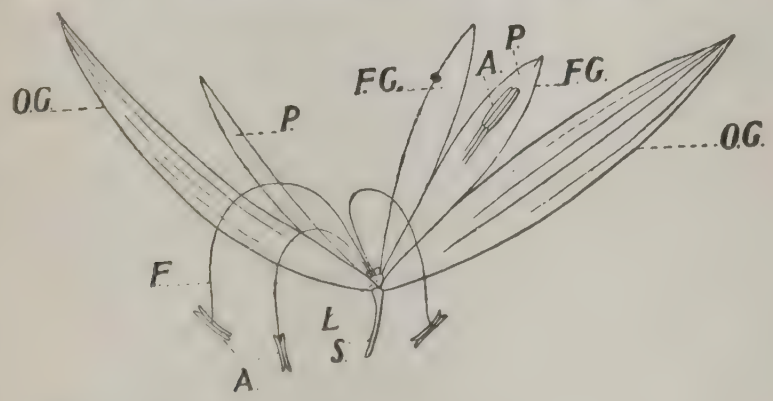


Fig. 97.—*Male spikelet of Maize.*

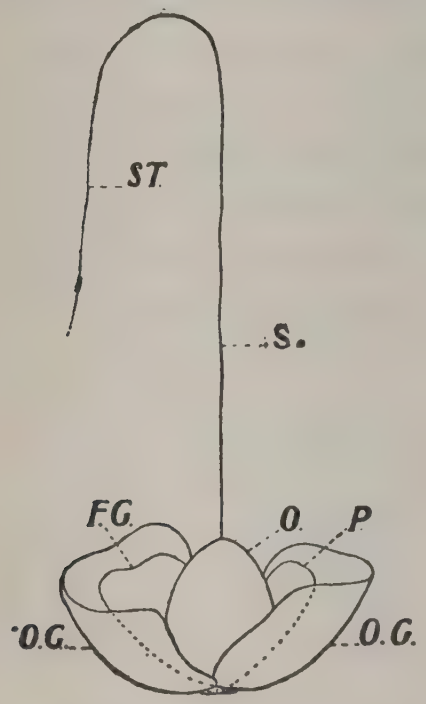
A.—Anthers.
F.—Filament.
F. G.—Flowering glume.
L.—Lodicule.
O. G.—Outer glume.
P.—Pale.
S.—Stalk.

The lower flower is the first to ripen. It consists of three stamens without any perianth unless we regard two small scales, the *lodicules*, as a very reduced perianth. When these lodicules swell they cause the bracts to separate, and allow the stamens to emerge.

The filaments, which are at first short, rapidly lengthen when the bracts separate.

The second pair of bracts enclosed in the outer glumes protects a similar three-stamened flower which will open when its fellow has withered.

The microspores which are dry and light, depend on the wind and gravity to reach the stigma of the pistillate flower.



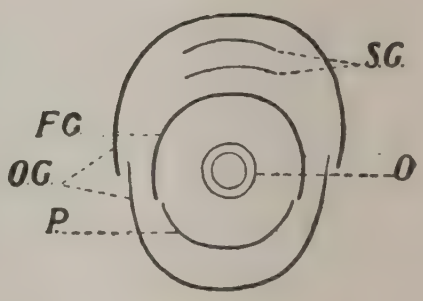


Fig. 98.—*Female spikelet of Maize.* Fig. 99.—*Diagrammatic transverse section of the female spikelet of Maize.*

F. G.—Flowering glume.
O.—Ovary.
O. G.—Outer glume.
P.—Pale.
S.—Style.
S. G.—Flowering glume and pale of sterile flower.
St.—Stigma.

Note how the large anthers are attached by their backs to the tip of the long and delicate filaments, so that even in calm weather they continually sway to and fro to scatter the pollen.

Note also that a large and tubular perianth would be a disadvantage in a wind-pollinated flower as it would only serve to collect rather than to distribute the microspores.

The pistillate inflorescence arises lower down on the stem as a lateral branch. It is a *spike* enveloped in several large leafy bracts.

Examine a young unripe inflorescence. Note the long hair-like styles which project as a silky tassel from between the bracts.

Strip off these large bracts and you find the spike composed of a large number of sessile flowers closely packed together on an enlarged and thickened axis. Each female flower consists of a single carpel, the unripe "grain of corn," enclosed in bracts homologous with those of the male flower. We find two outer glumes enclosing two inner pairs of bracts. One pair, consisting of a flowering glume and a pale, encloses the carpel, while the other pair is empty and represents the flowering glume and pale of an aborted flower. Not even a rudiment of this second flower is to be found in Maize, though such second flowers are the rule in other Grasses. There is no trace of a lodicule; there would be no use for lodicules as the stigmas are so well exposed.

No doubt the ancestors of the Maize plant of to-day produced inside each pair of outer glumes, two flowers one of

which gradually atrophied till now it has completely disappeared.

The carpel consists of a sessile ovary bearing a very long hair-like style which terminates above as a single stigma—an exceptional character, as almost all Grasses have two stigmas on each ovary.

The single ovule is large, completely filling the cavity of the ovary to the walls of which the coats of the ovule are universally adherent.

The fruit and seed are described on page 262.

THE FLOWER OF THE BEAN.

The calyx is a small cup formed of five united sepals as indicated by the five prominent teeth on its margin. As its sepals arise directly from the thalamus and are not adherent to the ovary, the calyx is said to be *inferior*.

The corolla consists of five brightly-coloured petals, the dorsal one of which is very large and folded over the other four. It is called the *standard* or *vexillum*. (Lat. flag.)

Laterally there are two oval petals called the *wings*. Ventrally we find two petals united along their ventral margin, but very easily separated. They have received the fanciful name of the *keel*. The whole flower is described as "papilionaceous" from its supposed-resemblance to a butterfly (Lat. *papilio*, a butterfly). As the petals arise directly from the thalamus they are described as *hypogynous* (Gr. *hypo*, below, *gyne*, the female, *i.e.*, pistil).

The stamens are ten in number, one being free. The filaments of the other nine are united throughout the greater part of their length to form a bundle.

The pistil consists of a single carpel or megasporophyll folded on its midrib, which is called the *dorsal suture* (Lat. *sutura*, a sewing or line of union) to form a central cavity. The ovary contains several ovules attached to what is homologically the margin of the carpellary leaf. The united margins are called the *ventral suture.*

The ovule has two coats surrounding a many-celled nucellus in which we find a large cell, the *megaspore.* As we have already seen, the nucellus is completely absorbed by the embryo in the ripened seed. As the pistil is inserted on the apex of the thalamus and is not adherent to the calyx it is described as *superior.*

Fruits that have a dry pericarp that dehisces, *i.e.*, splits open to allow the seeds to escape, are known as *capsules.*

The fruit of the bean is a one-celled capsule containing many seeds. It splits open not only along the ventral suture but also along its midrib (dorsal suture). This particular kind of capsule is called a *pod* or *legume.*

THE FLOWER OF TORENIA.

The calyx consists of five united sepals. The midrib of each sepal projects like a deep keel giving a winged appearance to the calyx. The five petals unite to form an irregular bell-shaped corolla with an upper lip of two petals and a lower lip of three.

We find only four stamens, the fifth (posterior or dorsal) one being absent or *suppressed.* Those present are in pairs, one pair with long, one with short filaments. The anthers of each pair are coherent to one another—a very unusual

arrangement. As the filaments are attached to the corolla, the stamens are *epipetalous*.

The pistil is superior and composed of two united carpels, one anterior and one posterior, a transverse partition dividing the ovary into two locules containing numerous minute ovules. The style is single surmounted by two stigmas which, as in Sunflower, remain with their receptive surfaces in close apposition till the ovules are ready for pollination. They then separate widely from one another and offer a remarkable instance of plant irritability. (See Fig. 100.) If gently touched with the point of a needle, the stigmas smartly close together. The same response occurs should an insect bearing pollen alight on the stigmas. They close together holding the pollen between them and remain in apposition till fertilisation has taken place.

Should however the stimulus be a false one, such as the touch of a needle or the leg of an insect free from pollen, the disappointed stigmas open again after a short interval. Examine the stigma with the low power and note the long projecting papillae between which pollen grains may be seen germinating.

The fruit is a dry, two-celled capsule derived solely from the ripened carpels and therefore described as *superior*. The seeds are numerous and minute, containing a quantity of endosperm. Note that the thalamus has grown up between the corolla and the base of the ovary, to form a small white collar or *disc*.

SUNFLOWER.

In the Sunflower we find an inflorescence or flowering

branch, the apex of which is expanded into a disc or *floral receptacle* upon which are crowded a large number of minute flowers so close together that the public mistake the whole inflorescence for a single flower. This kind of inflorescence is known technically as a *flower-head* or *capitulum* which is Latin for a little head.

You will best understand its structure by making a vertical section through the centre of the head and its stalk as in Fig. 101.

You see the apex of the stalk is expanded into a large disc on the upper surface of which are inserted numerous small sessile flowers of two kinds, (*a*) in the brown centre many tubular flowers known as the *florets of the disc*, (*b*) at the margin or periphery of the disc a whorl of larger yellow flowers with open strap-shaped corollas which you have perhaps at first mistaken for the petals of a single flower. These are distinguished as the *florets of the ray*.

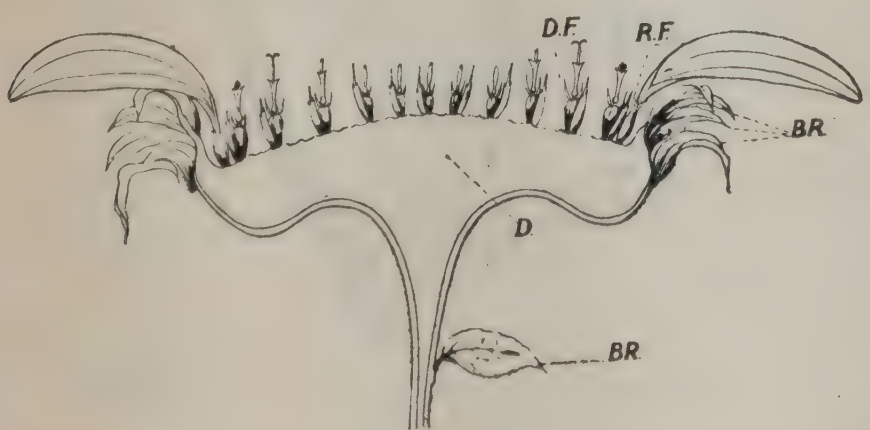


Fig. 101.—*Vertical section of the capitulum of Sunflower.*

Br.—Bracts.
D.—Disc.
D. F.—Disc floret.
R. F.—Ray floret.

On the under surface of the disc you find several whorls of pointed green *bracts*, known as the *involucre*, and which at first you perhaps mistook for the sepals of a single flower.

Pick off some of the florets of the disc. Notice that between the florets are a few scale-like bracts adherent to the disc. Note that the florets in the centre are the youngest or least advanced in development, those at the periphery, the oldest.

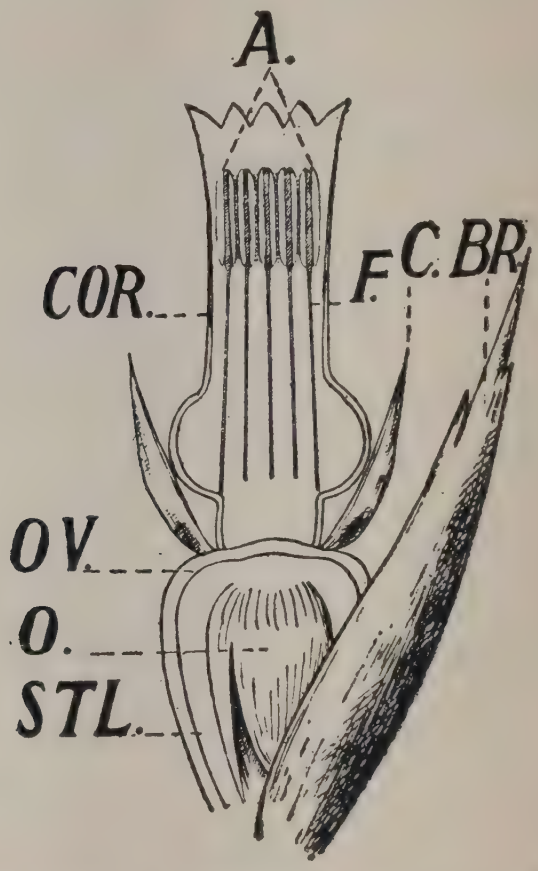


Fig. 102.—*A disc floret of Sunflower. The style and stigmas have not been drawn.*

A.—Anthers.
Br.—Bract.
C.—Calyx.
Cor.—Corolla.
F.—Filament.
O.—Ovule (megasporangium).
Ov.—Ovary.
Stl.—Stalk of the ovule.

Each floret is sessile, tubular in shape. The ovary occupies the lower part of the tube. The calyx and corolla are adherent to the outer surface of the ovary, so that they appear to spring from the top of the ovary. Hence the ovary is said to be *inferior*, the calyx *superior*, and the corolla *epigynous* (Gr. *epi*, above ; *gyne*, the female).

The limb of the calyx is reduced to two small membranous scales.

Fig. 103.—*A disc floret of Sunflower before the stigmas have separated.*

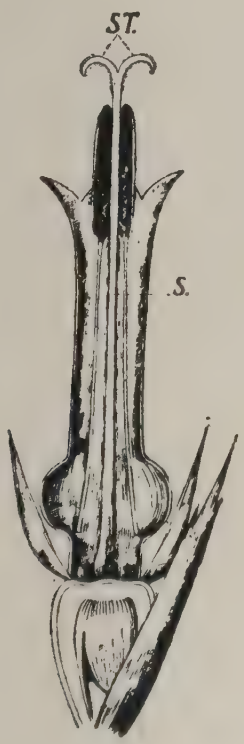


Fig. 104.—*A disc floret of Sunflower after the stigmas have separated.*

P.—Pollen grains pushed out by the tips of the stigmas.
S.—Style *St.*—Stigmas.

The tubular corolla consists of five united petals as indicated by the five teeth on its margin.

The stamens are five in number, their filaments are free. As they are inserted on the corolla they are said to be *epipetalous*. The anthers cohere by their margins to form a tube the bottom of which is closed by the unexpanded stigmas. (Fig. 103).

The pistil consists of a one-celled ovary containing a single ovule. It is surmounted by a Y-shaped style. There are two stigmas on the opposed surfaces of the forked style.

From analogy with other plants and the presence of two stigmas we conclude that the pistil originated as two carpels and that the cavities of their ovaries have united to form the single locule.

From the arrangement of the anthers closely surrounding the stigma, you might, at first, think self-pollination must take place as the pollen is shed into the tube of its anthers. It is however only the upper surface of the opened stigmas that is receptive to the microspores, and at first the two stigmatic surfaces are in close apposition.

The pollen of each flower ripens earlier than the stigma. Before the stigma ripens the style rapidly elongates. The outer and under non-receptive surface of the stigma is covered with minute hairs, which form a brush and sweep the pollen out of the tube before the stigma. When the pollen has been removed by an insect, the stigma lobes open and can then be pollinated by the microspores of another flower. (Figs. 103 and 104.)

The fruit contains a single seed. The pericarp is composed of the wall of the ovary surrounded by the remains of the calyx. It is therefore inferior. The fruit is dry and does not dehisce (split open) to discharge the seed.

The insertion and relative arrangement of the calyx corolla and pistil are the same in the florets of the ray, but the corolla is tubular only in its lower portion, the upper part is, as it were, split, to form a flat yellow ribbon or *strap-shaped* corolla of the five united petals. There are no stamens. In most of the florets there is neither style nor stigma; the ovary which is present contains no ovule but is barren. We call such flowers *neuter*.

We have here a good example of a peculiar type of colonial or social specialisation. While the dull flowers of the disc have specialised for the sole purpose of reproduction their unselfish fellows of the ray have given up all their reproductive organs and their sole function is to entice insects to ensure cross-fertilisation of the hermaphrodite flowers.

THE TISSUES OF THE FLOWERING PLANT.

In the young embryo the cells are all alike capable of dividing to form new cells, but as the tissues become differentiated, most of the cells of which they are composed lose their power of multiplying. Only in certain situations do we find collections of undifferentiated cells which have retained their embryonic character and are capable of dividing and producing new cells. Such collections of cells are known as *meristem* (Gr. *meristo*, to divide). They are to be found in the growing-points of the stem and root, and in certain

other positions where they are known as *cambium* layers (Lat. *cambio*, I change).

Both in the Ferns and in the Flowering Plants, the cells of the embryo soon become differentiated into three tissues :—

1. the Tegumentary,
2. the Ground or Fundamental, and
3. the Vascular tissue.

The tegumentary system is typically composed of a single layer of cells called the *epidermis*, (Gr. *epi*, on or outer : *derma*, skin) covering the outer surface of the plant body.

The outer walls of epidermal cells are generally thickened and cutinised. They may then often be peeled off in the form of a thin waterproof membrane called the *cuticle*. A cuticle is never present on the roots.

The margins of the epidermal cells are in close contact everywhere except at certain openings, the *stomata*, for the admission of air and the escape of vapour from the water which has been absorbed by the root and transfused to the surface of the leaves and of the younger stems. Each *stoma* (Gr. mouth), is bounded by a pair of green *guard-cells*, which, by the variation in their turgidity, open or close the stoma in response to the plant's requirements as described in the case of the Fern, p. 221.

In the Angiosperms the epidermis, except in the guard-cells, has few or no chloroplasts.

The arrangement of the ground and vascular tissues differs in the leaf, stem and root.

THE STEM.

Sunflower and Torenia.

Take an internode of Sunflower about as thick as your

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Fig. 105.—*Transverse section of part of an internode of the stem of Sunflower.*

C.—Cortex.
E.—Epidermis.
M.—Medullary ray.
P.—Pith.
V. B.—Vascular bundle.

Fig. 106.—*Part of the above more highly magnified.*

C.—Cambium.
Cor.—Cortex.
E.—Epidermis.
En.—Endodermis.
P.—Phloem.
Sc.—Sclerenchyma (Hard bast).
X.—Xylem.

little finger ; split it longitudinally in halves ; with the point of a blunt knife, pick away the succulent ground tissue ; a number of longitudinal whitish strings are left ; these are the vascular bundles.

Make transverse and longitudinal sections as thin as you can, from a similar piece of stem that has been preserved in spirit for some days to remove the *resin*, chlorophyll and bubbles of air which, when present, obscure the appearance of the tissues.

The epidermis is seen as a single layer of roughly cubical cells, except in places where its cells have grown out to form multicellular *hairs*. Stomata are seen scattered here and there, much more sparsely than on the leaves.

The presence of the vascular bundles naturally divides the ground tissue into three regions (Fig. 105) :—

(1) A central *pith* or (Lat.) *medulla* lying *internal* to the bundles.

(2) A peripheral *cortex*, (Lat. bark, outer layer), lying *external* to the bundles.

(3) *Medullary rays*, lying *between* the bundles, so called because in transverse sections, the tissue is seen radiating out from the pith like the spokes of a wheel to join the cortex.

The portion of the cortex immediately beneath the epiderrmis consists of several layers of cells which have their walls thickened at the angles where three or more cells meet. This tissue is called *collenchyma* (Gr. *kolle*, jelly). Collenchyma is generally found in situations where strength combined with elasticity is required. (Fig. 106.)

Internal to the collenchyma, the other cells of the cortex

present a contrast by leaving intercellular air-spaces between their unthickened angles. The transition from collenchyma to this *cortical parenchyma* is not sharply marked, the one merging into the other. The quantity of protoplasm and the number of chlorophyll bodies gradually diminishes from without inwards as we pass through the cortex and the medullary rays till we reach the central pith.

Here the cell-walls are very thin and the protoplasmic contents so small that some cells near the centre are empty.

Here and there throughout the ground tissue, *resin ducts* are seen as longitudinal strands of small thin-walled cells containing resin. In sections preserved in alcohol, the resin is removed in solution.

Observe the innermost layer of the cortex on which the vascular bundles abut, the *endodermis* or *bundle-sheath.* This is difficult to recognise in older stems, but in the root and in young stems or branches less than 4 mm. in diameter, is easily observed as a continuous layer of thin-walled cells with a characteristic dark dot on their radial walls due to refraction of light by the undulating character of the wall.

Inside the sheath we find the vascular bundles arranged as a ring of wedges, their points inward.

External to each bundle we find in the Sunflower a thick strand, semicircular in section, of lignified, thick-walled spindle-shaped cells, the *sclerenchyma* (Gr. *skleros*, hard).

These cells contain little or no protoplasm and their walls are in some places so thick that little lumen is left. Their function is to add rigidity to the stem. This sclerenchyma is sometimes called the *hard bast* to distinguish it from—

(*a*) the true or *soft bst*, the *phlœm*, which lies immediately inside the sclerenchyma and is made up of —

(1) *Sieve-tubes*—long tubes with thin walls of cellulose. They are so-called because their lumen is interrupted here and there by oblique or transverse septa in which are many perforations. These *sieve-plates* are found not only as septa but also sparsely here and there on the side walls of the tubes. They can be made more prominent by stains such as iodine or chloro-iodide of zinc, both of which stain the plates brown, while the latter stains the lateral walls of the tubes blue. The tubes contain protoplasm which is most abundant near the sieve-plates. Thread-like processes passing through the perforations of the sieves give a continuity to the cytoplasm of contiguous cells. Staining with eosine or safranin shows up this protoplasm in longitudinal sections.

(2) *Companion-cells* lying in close contact with the sieve-tubes of which they are the sister cells having been cut off from them in development from common mother-cells.

(3) *Bast parenchyma.*—In transverse section its cells look like sieve-tubes except that they are smaller and have no sieve-plates. All the cells of the bast contain protoplasm, and their walls are all of cellulose.

The sieve-tubes of the Gourd and Cucumber are much larger and more easily observed than those of Sunflower. Sections should be made from the stem of the Gourd preserved in alcohol and stained with eosine. Leave other sections for a few minutes in an acid solution of Aniline Chloride. All the lignified walls take on bright yellow colour. The arrangement of the bast in these plants is anomalous as we find bast both on the outside and on the inside of the wood in each bundle.

(*b*) The wood which consists of—

(1) *Vessels* readily recognised in transverse sections by their wide cavities. They are arranged in rows radiating from the centre, where those of smallest calibre are to be found. They increase in width towards the periphery. Each vessel originally consists of a number of cylindrical cells containing protoplasm, arranged longitudinally, end to end, but the protoplasm soon disappears and the transverse cell-walls become absorbed ; the result is the continuous hollow tubes we call *wood vessels* or *ducts*, consisting of merely dead cell-wall.* These cell-walls become thickened and altered in composition by the deposit of lignin in their original cellulose. These thickenings vary in their pattern. We have seen scalariform thickening common in the tracheid* of Ferns, dotted and pitted tracheids common in Cycas. In radial longitudinal sections of Sunflower stem we note the absence of transverse walls in the wood vessels. Vessels close to the

* When a single cell fulfils the functions of a multicelled duct it is distinguished by the name *tracheid*. (Gr. *trachea*, vessel : *oidos*, like.)

pith may be seen with thickening in the form of rings (annular vessels). Others are marked with spiral thickening, the spirals being, some closely, some loosely coiled (spiral vessels). The largest and most peripheral vessels show oval thin spots here and there on their wall (pitted vessels). In others the pits are elongated transversely.

(2) *Wood-fibres* seen in longitudinal sections as long, pointed cells with pits on their lignified walls. In transverse section these walls are seen to be thick with little or no contents in their lumen.

(3) *Wood-parenchyma*, cells which retain their protoplasm and whose walls may or may not be lignified.

The various forms of thickening of the vessels have no great importance for the student of elementary biology. The most important facts for him to grasp are that both wood and bast vessels form continuous channels from the rootlets through the stem to the leaves; that the water with its dissolved salts which has been absorbed by the roots ascends as thin sap through the wood-vessels and tracheids of the stem and of the leaf-veins to the parenchyma of the leaf. Though the cells of which the vessels are formed are dead, they perform this very important function.

From the leaf parenchyma the excess water evaporates into the intercellular spaces of the spongy tissue and escape by the stomata.

In moist weather the guard-cells are turgid and wide apart, so that transpiration takes place freely. In very dry weather the guard-cells lose their turgidity and become flaccid and flat till their free margins come in contact and close the stoma. In this way excessive transpiration and consequent withering is prevented.

The sap containing the proteids and sugar which have been manufactured in the leaf by photosynthesis, *i.e.*, under the influence of the sunlight descends through the bast to the stem, roots or wherever it may be required.

Between the bast and the wood we find the *cambium*, a layer of meristem whose individual cells are arranged in radial rows. Their walls are of cellulose and very thin especially the outer and inner walls. Their outline is oblong, the short axis being radial.

This cambium layer is of great importance ; being of an embryonic or formative character it is capable of dividing to form new cells. The cells cut off from its inner surface develop into wood, those on the outer surface into bast.

All Dicotyledons and Gymnosperms possess a cambium layer in their vascular bundles and are therefore able during periods of growth to form new wood and phloem cells and so add to the thickness of their stems. From the position of the cambium, it follows that all new layers of wood lie outside those previously formed, all new bast inside the older layers. As growth in the monsoon is much more energetic than in the cold weather, the character of the wood formed in these seasons differs, with the result that cylinders of

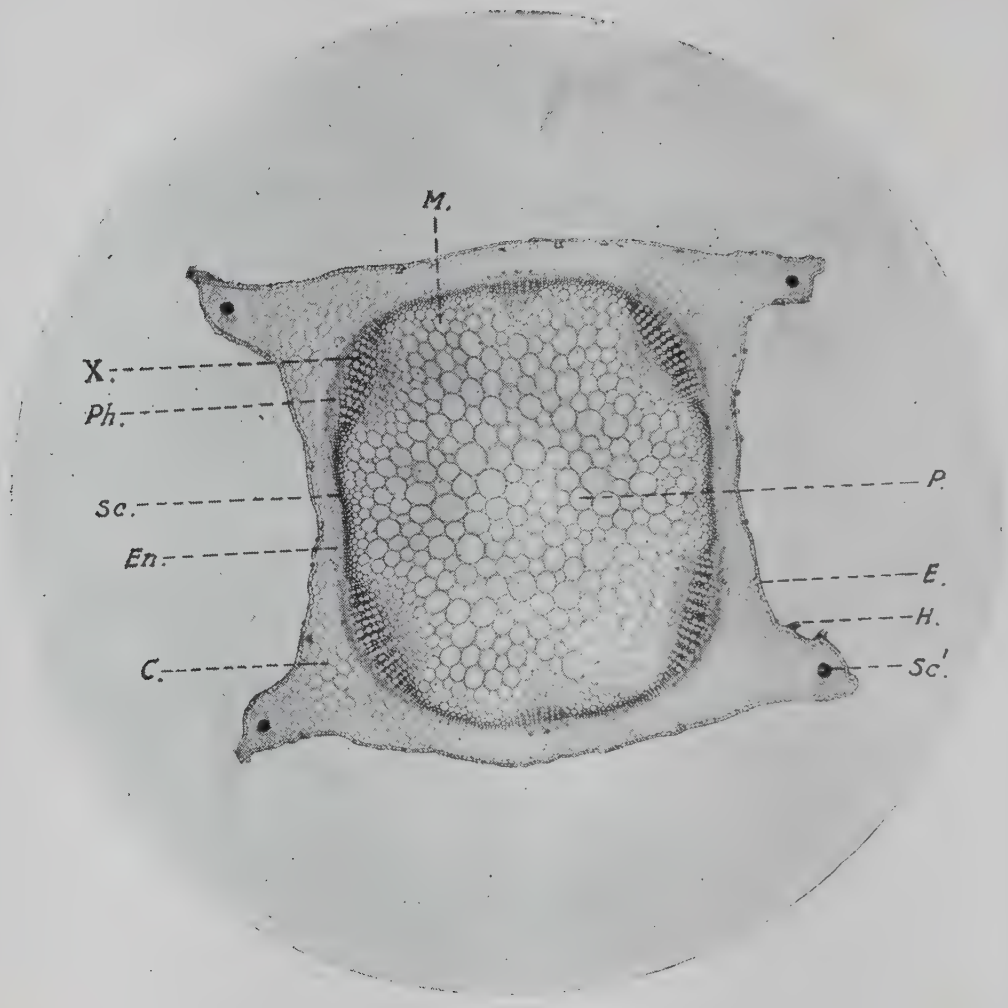

Fig. 107.—*Transverse section of an internode of the stem of Torenia.*

C.—Cortex.
E.—Epidermis.
En.—Endodermis.
H.—Hair.
M.—Medullary ray.
P.—Pith.
Ph.—Phloem.
Sc.—Sclerenchyma.
Sc'.—Cord of sclerenchyma in cortex.
X.—Xylem.

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different consistence and shade of colour are formed each year, showing as rings in transverse sections of the stem. We can thus tell the age of a tree by counting the number of rings in the wood. The "grain" of the wood is due to the fact that we can split it more easily in the lines of the softer wood.

In a young stem we find the individual vascular bundles are quite isolated ; there is no interruption in the medullary rays between the pith and the cortex. In older stems we find that the cells of the medullary rays between the cambium layers of adjacent bundles have become merismatic and are dividing to form wood on their inner, bast on their outer face. This region has in fact becomes a layer of *interfascicular* cambium and a continuous cylinder (ring in section) of cambium has resulted. In Sunflower this interfascicular (Lat *inter*, between ; *fascicula*, bundles) cambium is not very active. It can be better studied in stems of Castor Oil plant or of Aristolochia.

The tissues in the stem of Torenia are arranged on the same general plan as in Sunflower.

Make transverse sections near the middle of an internode.

Note the quadrangular outline. Each corner stands out as a buttress, so that the sides may appear somewhat concave. Note from without inward :—Fig. 107.

(1) The epidermis as in Sunflower, a single layer of cells in close contact, with their outer wall thickened and cutinised to form a cuticle. There are no chloroplasts in the epidermis

except in the guard-cells of the stomata. The hairs are much fewer; each forms a narrow sharp-pointed cone of two or three cells.

(2) The cortex thick at each angle, narrows to a layer three or four cells in thickness midway between the angles. In the cortex observe :—

(*a*) In each corner a cord of colourless thick-walled sclerenchyma fibres with small empty lumina. These fibres are so hard compared with the soft surrounding cortex that they are often torn out of the section by the edge of the razor.

(*b*) The cortical parenchyma with intercellular spaces.

(*c*) Endodermis, as usual, a single layer of cells containing starch grains. In old stems the radial walls are marked by the characteristic dot.

(3) The central cylinder. The ground-tissue including pericycle, rays and the large pith, resembles that of Sunflower, but the sclerenchymain stead of being collected into thick strands outside each bundle forms an almost continuous cylinder.

The vascular bundles are six in number, four large in the same radii as the angles, two small at the centre of opposite sides.

STEM OF MAIZE.

As there is no cambium layer in the vascular bundles of the Monocotyledons, their stems can only increase in

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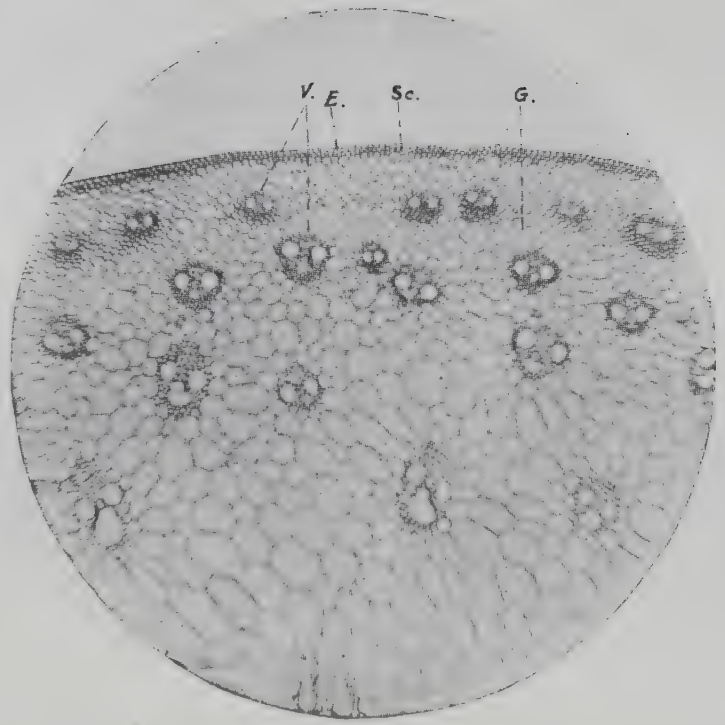

Fig. 108.—*Transverse section of part of an internode of the stem of Maize.*

E.—Epidermis.
G.—Ground-tissue.
Sc.—Sclerenchyma.
V.—Vascular bundles.

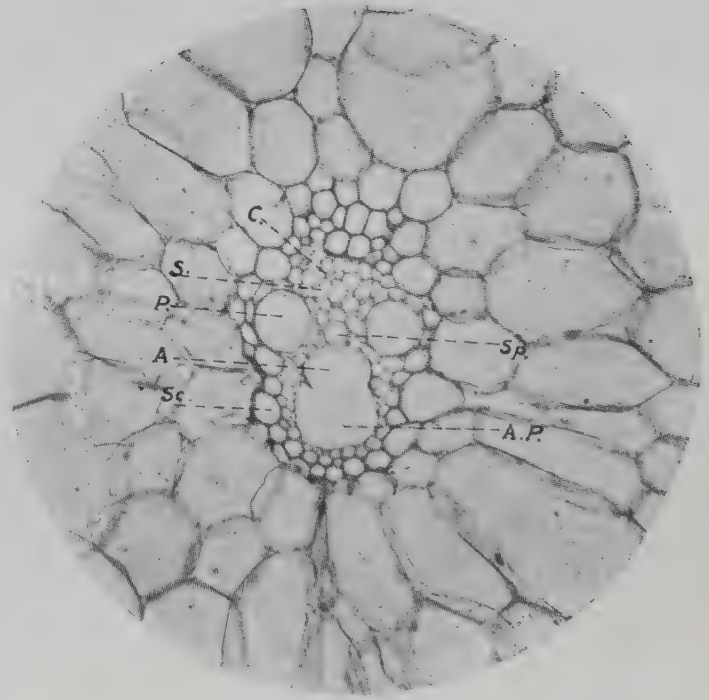

Fig. 109.—*A vascular bundle of the above more highly magnified.*

A.—Annular vessel.
A. P.—Air passage.
C.—Companion-cell.
P.—Pitted vessel.
S.—Sieve-tube.
Sc.—Sclerenchyma sheath.
Sp.—Spiral vessel.

thickness by the growth in size of the already formed cells. No increase can take place by the production of new cells, either wood or bast.

Cut transverse and longitudinal sections of one of the lower internodes of a well-grown stem of Maize that has lain in alcohol for some days.

With a magnifying glass note that the vascular bundles are very numerous and dotted about the ground-tissue, so that transverse sections do not show the latter divided into definite cortex and pith.

Note that the bundles are smaller and more numerous near the periphery than in the more central part. (Fig. 108).

With the microscope note in the transverse section :—

(1) An outer brown cuticle on the outer walls of—

(2) The epidermis, a single layer of cells varying in size but all with their margins in close contact except at the stomata. Observe the stomata have both guard and subsidiary cells as more fully described in the leaf.

Some of the epidermis should be peeled off a fresh stem and mounted in water. Note the oblong shape of its cells and the absence of chloroplasts.

3) Below the epidermis observe the sclerenchyma composed of elongated cells, seen in transverse section to have thick, refractile, lignified walls. Note that there is a break in the continuity of the sclerenchyma below each stoma where we find an intercellular air space.

(4) Below the sclerenchyma the ground-tissue consists of thin-walled parenchyma with air spaces at the angles of the cells. Like Sunflower the outer layers have chloroplasts and abundant protoplasm. As we trace them inwards the cells contain less and less protoplasm till in the centre we can see hardly any.

(5) Select one of the large vascular bundles near the centre. (Fig. 109).

(*a*) Observe a sheath of sclerenchyma round each bundle.

(*b*) The wood-vessels; two very large vessels arranged side by side, and two smaller in the same radius, situated internal to and between the larger vessels. In longitudinal sections the larger two vessels are seen to have pitted markings on their walls. Of the others the innermost has generally annular thickening, the fourth, spiral thickening.

Around and between the larger vessels is a group of tracheids with thick, lignified and pitted walls.

Around the inner vessel are grouped cells with thin cellulose walls, the wood-parenchyma. In older bundles a large intercellular space is often formed by the splitting apart of these cells. In this case the thickening ring of the vessel for want of support may

fall out of the section or be pushed out of place by the edge of the razor.

(*c*) The phloem lies in the angle between the two large wood-vessels. It consists of sieve-tubes and companion-cells only. There is no bast parenchyma.

As in Monocotyledons generally, there is no cambium layer. Hence the stem cannot increase its thickness by the formation of new wood or bast.

THE LEAF.

Sunflower and Torenia.

Make transverse sections of the leaf-stalk of Sunflower, both fresh and preserved in alcohol.

The arrangement of the tissues in the leaf-stalk in its chief details resembles that of the stem with the following exceptions :—

The leaf-stalk is not regularly cylindrical but grooved on its upper surface. Its symmetry, like that of the leaf-blade, is dorsi-ventral in contrast with the radial symmetry of the stem and root.

The epidermis with its hairs resembles that of the stem, but stomata are more numerous.

Below each stoma the collenchyma is interrupted by a large intercellular space surrounded by thin-walled parenchyma.

In the stem the xylem lies internal to the bast ; as the bundles of the stem and leaves are continuous, it naturally follows as they bend outward into the leaf that the xylem

comes to occupy the upper, the phloem the lower position in the leaf.

There are usually only three large and several small bundles in the leaf-stalk. They are not arranged in a ring but in a crescent with its concavity upwards in correspondence with the groove on the upper surface of the stalk.

There is no cambium in the smaller bundles. That present in the three larger bundles lasts only a short time, so that in an older leaf-stalk we find no cambium.

Take a small piece of the leaf-blade of Sunflower that has been preserved in alcohol. Either embed it in paraffin or enclose it in a slit in a piece of carrot. Cut thin sections at right angles to its main vein. Mount the thinnest in glycerin. (Fig. 110).

Beginning with the upper surface, note :—

(1) The epidermis as in the stem, a single layer of cells but better defined. The outer surface of the cells forms a cuticle ; stomata are numerous, so are the multicellular hairs.

(2) Enclosed between the upper and lower layers of epidermis we find the ground tissue of the leaf called the *mesophyll*, (Gr. *mesos*, middle ; *phyllon*, leaf) in which ramify smaller vascular bundles, the *veins*.

(*a*) The cells of the mesophyll immediately below the epidermis of the upper surface form two layers of thin-walled, elongated cells with copious protoplasm and chloroplasts. The long axes of the cells are arranged perpendi-

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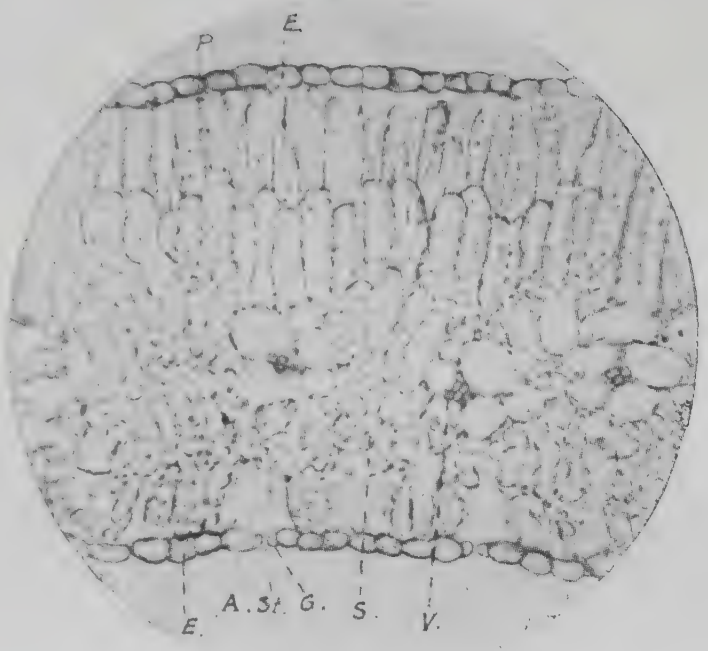

Fig. 110.—*Transverse section of the leaf-blade of Sunflower.*

A.—Air-space.
E.—Epidermis.
G.—Guard-cell.
P.—Palisade parenchyma.
S.—Spongy parenchyma.
St.—Stoma.
V.—Vascular bundle.

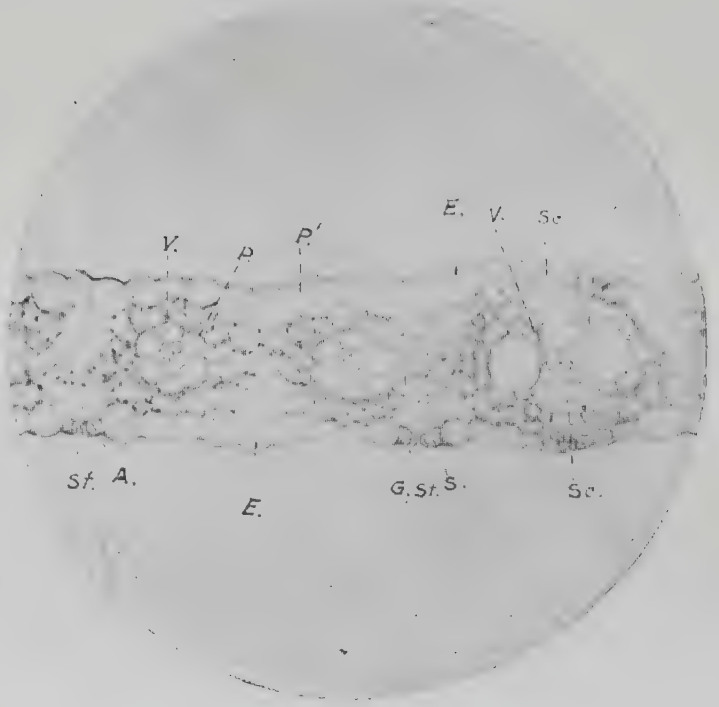

Fig. 111.—*Transverse section of the leaf-blade of Maize.*

A.—Air-space.
E.—Epidermis.
G.—Guard-cell.
P.—Parenchyma devoid of chlorophyll bodies.
P'.—Parenchyma containing chlorophyll bodies.
S.—Subsidiary cell.
Sc.—Sclerenchyma.
St.—Stoma.
V.—Vascular bundle.

cular to the surface of the leaf, hence they are called the *palisade* cells.

(*b*) The remainder of the mesophyll between the palisade cells and the epidermis of the lower surface is composed of parenchymatous cells of irregular shape with large intercellular spaces. Hence this portion is called the *spongy tissue*. These cells also contain many chloroplasts.

(3) The veins, since they form a network, may be seen in the section cut transversely, longitudinally or obliquely. They are the smaller vascular bundles and may be reduced to only a single tracheid with spiral or pitted markings. Each is surrounded by parenchymatous cells devoid of chloroplasts.

(4) The lower layer of epidermis has even more stomata than that of the upper surface. Each stoma opens into a large air-space which communicates freely with the intercellular spaces of the spongy tissue.

The leaf of Torenia resembles that of Sunflower but the hairs are fewer and of the same type as those on the stem of Torenia. The upper layer of the mesophyll forms a typical palisade ; the next layer is mostly of elongated cells enclosing intercellular spaces and forms a tissue intermediate between palisade and spongy parenchyma.

LEAF OF MAIZE.

Observe the parallel venation ; the margins are rough to the touch from the presence of numerous silicified hairs.

With the low power of the microscope observe that these bristles all point toward the apex at an acute angle: and that the margin of the leaf is strengthened by sclerenchymatous cells free of chlorophyll.

Double a piece of the lamina tightly over your left index finger and with a sharp razor shave off from the under surface a thin section, if possible only removing the epidermis. Mount in water or glycerin.

Observe the sinuous outline of the oblong epidermal cells which contain no chloroplasts.

Note the stoma enclosed by narrow, crescentic guard-cells containing many chloroplasts.

Note that the convexities of the guard-cells are in turn surrounded by triangular *subsidiary cells*.

Cut transverse sections of both fresh and spirit-preserved portions of the leaf-blade. (Fig. 111).

I. Note the epidermis on both surfaces consists of a single layer of oblong cells with wavy outlines.

The stomata are numerous except above the vascular bundles on both surfaces.

The two subsidiary cells completely surround the narrow guard-cells. They are thin and help to roof over a large air-space.

Observe the hairs, mostly unicellular; some of the larger are seated on a cushion of outgrowing epidermal cells.

Peel or cut off some of the upper epidermis. Leave for some time in strong nitric acid; wash in water; dry; ignite on platinum over a flame; examine

the residue in water under the microscope. You find you have not destroyed the walls of the epidermal cells. A skeleton still remains composed of silica with which the cellulose has been impregnated.

II. Note that the mesophyll does not form a palisade layer. The greater bulk consists of—

(*a*) Chlorophyll-containing cells with numerous intercellular air-spaces.

(*b*) Some of the parenchyma is composed of colourless cells, without chloroplasts and without intercellular spaces, forming a sheath around the bundles.

(*c*) Elsewhere below the epidermis and especially near the mid-rib we find groups of these colourless cells. In the leaf-sheath this colourless parenchyma forms the greater part of the mesophyll.

III. Observe on both upper and lower surfaces of the larger vascular bundles, thick strands of sclerenchyma which extend to the epidermis, and with the bundles form complete struts across the leaf, adding very considerably to its rigidity. Some such arrangement is obviously necessary in long, narrow strap-shaped leaves which, without it, would collapse under their own weight. The larger vascular bundles resemble those of the stem in structure. The ringed and spiral vessels are nearest the upper surface.

THE ROOT.

Bean.

The tap-root of Sunflower is small in the young seedling. The structure of the root can be more easily studied in the Bean.

Sow some Beans in damp sawdust and when the primary root has reached a length of about 50 mm. examine it and note :—

Several lateral roots have been given off in four longitudinal rows. The oldest are the uppermost, the youngest nearest to, but a considerable distance from the tip. The region near the tip has not given off any secondary roots.

Note that the oldest parts of the roots hold on to the sawdust owing to the presence of root-hairs.

The younger parts near the tip are clean of sawdust or particles of soil owing to the absence of root-hairs.

Harden in alcohol for about a week.

Make transverse sections about 40 mm. from the tip. Mount in glycerin. Some sections should be cleared in weak solution of potash. (Fig. 112).

Note on the external surface of the section a single layer of ill-defined cells some of which have grown out as long thin-walled *root-hairs*. Hence this layer is called the piliferous layer. (Lat. *pilus*, a hair : *fero*, to bear.) The function of this layer is to absorb the water with its dissolved salts from the soil. As already stated its walls are never cutinised, thus contrasting with the epidermis of the leaf and stem.

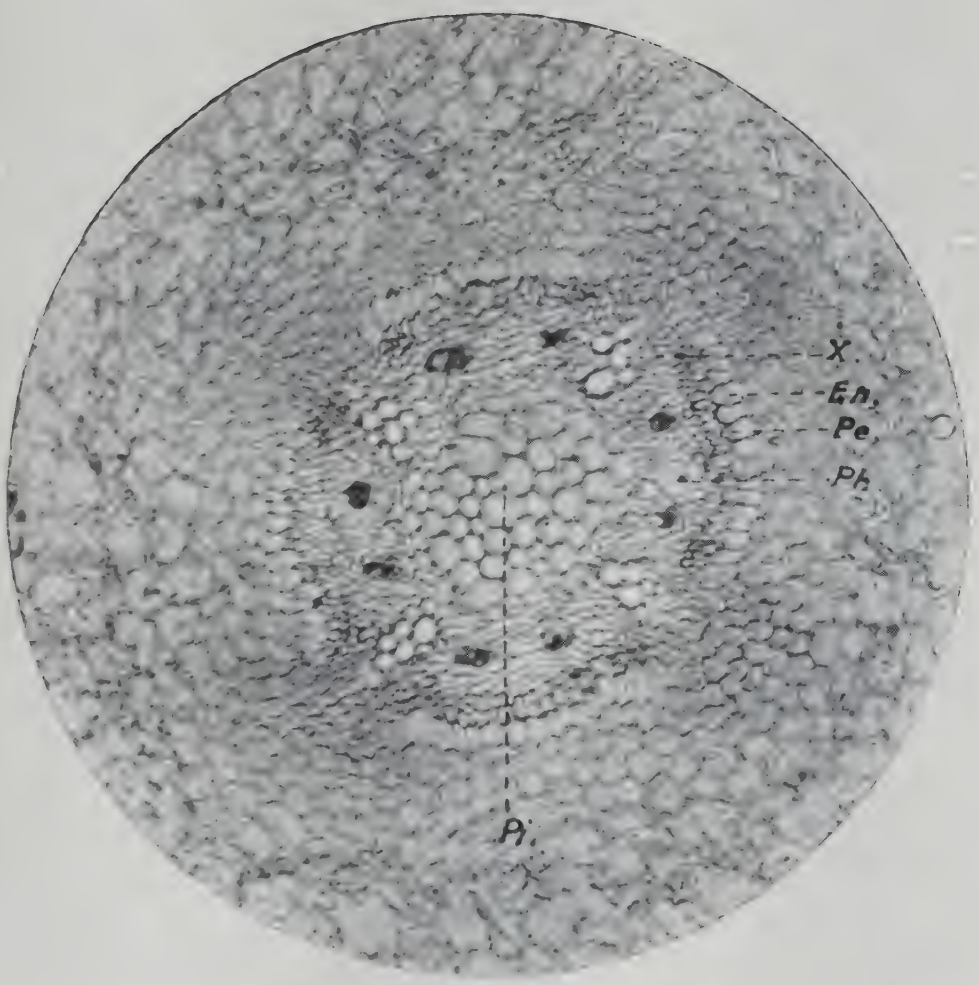

Fig. 112.—*Transverse section of the root of Bean showing the central region.*

En.—Endodermis.
Pe.—Pericycle.
Ph.—Phloem.
Pi.—Pith.
X.—Xylem.

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Internal to the piliferous layer is a very wide *cortex* of colourless parenchyma cells with intercellular spaces.

The innermost layer of the root cortex is a well-defined *endodermis* with characteristic dark dots on the lateral walls of its component cells.

The ground-tissue of the central cylinder inside the endodermis is divided into three regions :—

(1) That *outside the bundles*, the *pericycle*, a single layer of thin-walled cells opposite the phloem, two or three cells thick opposite the wood in the Bean root.

(2) That *between the bundles*, the *medullary rays*, eight in number, between the bast and the wood joining the pericycle with—

(3) The *pith*, the *central* portion ; composed, as in the stem, of thin-walled parenchyma.

The wood and bast strands alternate with one another in contrast with the stem where the wood lies internal to the bast. The vessels and cells of both wood and bast are of the same character as in the stem.

Cut transverse sections well away from the tip of an older root of Bean or Sunflower avoiding the origin of any lateral roots.

Observe that the primary phloem and wood have developed and that the cells internal to the phloem have become merismatic—have formed a *cambium ring* with the wood on the inside and bast on the outside. Four large wedges of secondary wood have been formed on the inner aspect of the cambium. They are separated from one another by

rays of ground-tissue which lie in the same radii as the primary wood.

On the outer surface of the cambium secondary bast has been formed.

Note that the outer surface of the older root is bounded by a narrow layer of *cork* composed of square or oblong cells containing no protoplasm. The walls of the cork-cells are in close apposition leaving no intercellular spaces. Their cellulose has been converted into a substance called *suber* (Lat. cork), which as you know, from its use as stoppers for bottles, is impervious to fluids and gases. Consequently all the tissues external to the cork, *viz.*, the endodermis, the cortex and the piliferous layer, as they now receive no nourishment from the sap, have dried up, died and fallen off.

The cork has been formed from the pericycle which developed a merismatic layer, the *cork-cambium*.

Sections should also be examined to see the origin of the lateral roots. They are seen to arise from the pericycle opposite the groups of primary wood. This accounts for their arrangement in the Bean in four rows. In addition to the pericycle the endodermis and a little of the cortex enter into the formation of the lateral roots. The lateral roots can be seen in all stages boring their way through the cortex.

THE ROOT APEX.

Roots contrast with stems in that the meristem which constitutes the *growing point* is never naked, but always covered over by a *root-cap*.

Thin longitudinal sections should be made through the tip of the radicle in germinating seeds of Sunflower or Bean. The sections are best made after embedding in paraffin or celloidin, but fairly satisfactory sections can be made with a razor longitudinally through the radicle in fresh or soaked large seeds like the Sword-Bean, where the fleshy cotyledons act as embedding material. Only strictly median sections are of any use, as tangential sections may pass outside the growing point.

Select with a low power, a median section from those you have cut. Clear with weak solution of potash or with *eau de Javelle.* Mount in glycerin ; examine with a low power. Observe that the bulk of the tissue is arranged in longitudinal rows of cells which converge to meet a short distance from the apex in a mass of small cells, the *growing point.*

There is no special apical cell as in the Fern. As the cells of the meristem divide they give off new cells in all directions. Those toward the apex die off and form a root-cap of several layers. As the root bores through the soil, the outer cells of the cap are constantly rubbed or worn off and replaced by the growing point.

At the proximal side the cells given off from the growing point soon become differentiated into the longitudinal rows which represent the epidermal or piliferous layer, the cortex and the central cylinder.

The Root of Maize resembles that of the Dicotyledons with certain important exceptions. There is never any formation of cork, hence the cortex persists and the appearance of the root is practically the same whether we make our

sections near the tip or high up near the stem. (Fig. 113).

There is no cambium and therefore no secondary formation of wood or bast.

In a transverse section (from without inward) we find—

(1) The piliferous layer, many of its cells grown out as long root-hairs. This layer is not homologous with the epidermis but is really the outermost layer of—

(2) The cortex, a very broad layer in Maize.
Its inner layer is a characteristic endodermis.
In old roots the inner and radial walls of the endodermis become thickened and lignified.

(3) The central cylinder. Its outer layer—

(*a*) the pericycle will be made more obvious by treating with iodine as its cells contain many starch grains.

(*b*) the bast and (*c*) the wood consist of many, from nine to twenty, strands which alternate with one another as in the Dicotyledon.

(*d*) Centrally there is a large pith.

NUTRITION.

Chemical analysis of green plants shows that a large number of elements enters into their composition—carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, sodium, potassium, calcium, magnesium, iron, chlorine, silicon and others, though not all of these are essential to the life and growth of the plant.

The plant obtains these from its environment, *viz.*, the soil and atmosphere, or in the case of aquatic plants from

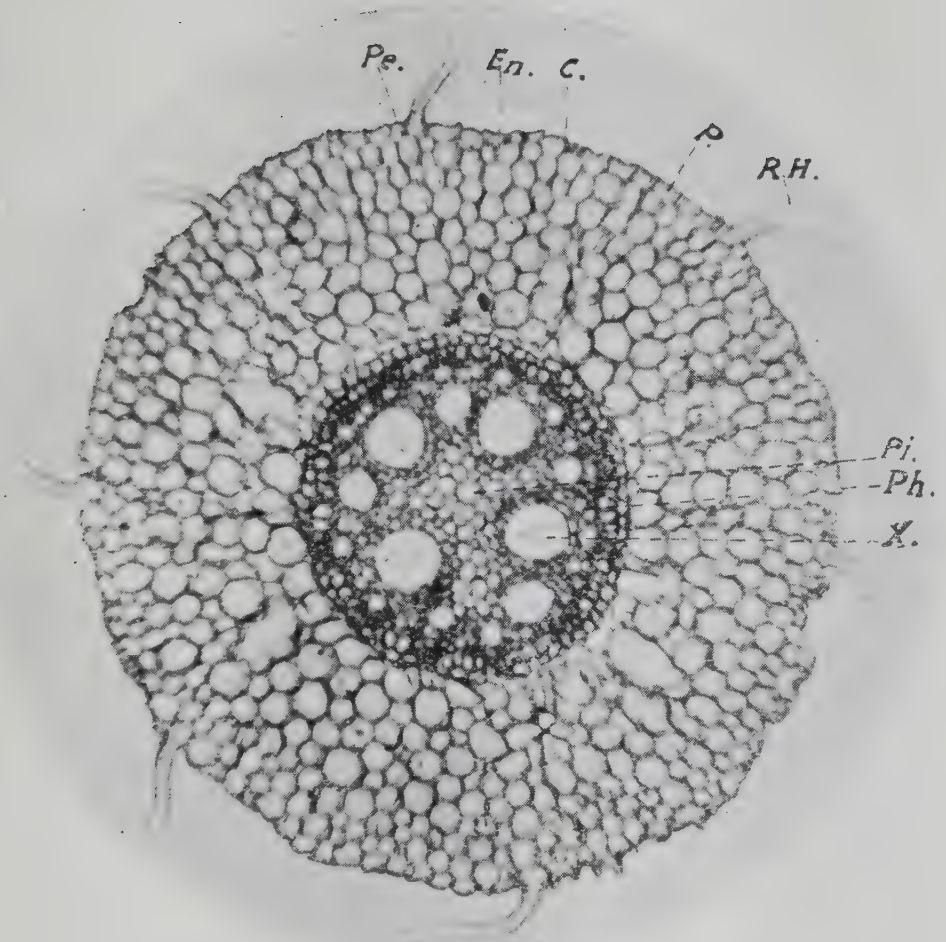

Fig. 113.—*Transverse section the root of Maize in the region of the root-hairs.*

C.—Cortex.
En.—Endodermis.
P.—Piliferous layer.
Pe.—Pericycle.
Ph.—Phloem.
Pi.—Pith.
R. H.—Root-hair.
X.—Xylem.

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the water. Its carbon is derived solely from the CO_2 of the atmosphere. If the root is kept immersed in a jar of Knop's solution the plant will live and grow, but if the leaves be exposed to air deprived of CO_2 it dies, even if some carbon compound is added to the solution in which the root is immersed. The foliage leaves are the principal organs for assimilating CO_2 and for this purpose they are provided with numerous stomata and intercellular spaces to admit air which normally contains some CO_2.

The soil furnishes the other elements in the very dilute watery solution of inorganic salts absorbed by the root. Thus hydrogen and oxygen are derived from water, and the remaining elements from the nitrates, phosphates, sulphates, chlorides and silicates of sodium, potassium, calcium, magnesium and iron held in solution in the water.

Though nitrates are the usual source of nitrogen supply, some plants belonging to the Bean family obtain it also from the nitrogen of the atmosphere through the agency of certain bacteria living in small nodules on their roots. These bacteria take up nitrogen from the air permeating the soil, and build up soluble nitrogen compounds which are absorbed by the plant. The latter provides the bacteria with the food which they require. Such a condition of two organisms living together to their mutual advantage is known as *symbiosis*.

Carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, iron, potassium, calcium and magnesium are elements essential for the normal growth of most green plants. The first six enter into the composition of protoplasm ; iron is essential for the formation of chlorophyll ; potassium, calcium

and magnesium are in some way necessary for the synthesis or distribution of carbohydrates.

That these elements are essential can be shown by attempting to cultivate plants in an artificial environment. In this way we can deprive the plant of any chemical compound which supplies a particular element. Thus a green plant cannot be grown in an atmosphere containing no CO^2. To demonstrate this place a green plant under an inverted jar in bright sunlight, and draw through the jar a slow current of air which has traversed a bottle containing fragments of caustic potash. The latter deprives the air of CO_2. We find there is no growth. Prepare some Knop's solution from which iron is completely excluded, and cultivate a seedling with the root immersed in a jar of this liquid. You will find there is no development of chlorophyll, the plant remaining colourless or yellow. On adding a trace of an iron salt to the solution the green colour will appear. Similarly the omission of any one of the other elements contained in Knop's solution interferes with normal growth.

The finer ramifications of the root bear on their surface hair-like prolongations of the superficial layer of cells. These *root-hairs* usually break off when a plant is pulled out of the soil, but if some seeds are allowed to germinate on moist blotting-paper or saw-dust these hairs will be well seen on the primary root. The root-hairs come into intimate contact with the particles of the soil, which are covered with a thin layer of water which is never pure, but is a dilute solution of various inorganic and organic substances.

Some of the inorganic substances pass with the water into the root-hairs by the process of osmosis, while substances not required by the plant are kept out by the selective action of the living protoplasm contained in the root-hairs. Were it not for this selective action injurious or unnecessary substances would be absorbed, or concentrated solutions in the soil would produce an osmotic current in the reverse direction and deprive the plant of its liquid content.

As absorption proceeds the cells of the cortex become turgid with crude sap. A small part of this passes up the plant through the ground-tissue by diffusion from cell to cell. The greater portion enters the xylem vessels which conduct it through the root and stem into the xylem vessels of the leaf-veins, from which it diffuses into the mesophyll of the leaf. This upward current of the sap from the root to the leaves is called the *transpiration current.*

From the leaf parenchyma the excess water evaporates into the intercellular spaces of the spongy tissue and escapes by the stomata. This process of elimination of the surplus water as vapour through the stomata is called *transpiration.*

The passage of the solution from the cortical cells into the xylem of the root is not solely due to osmosis. The probable explanation of this phenomenon is that when the turgidity of the cortical cells reaches a certain limit their protoplasm contracts and drives the cell-sap with considerable force into the xylem vessels. The flaccid cells again become turgid by further absorption and the process is repeated. This intermittent pressure exerted by the cortex of the root is known as *root-pressure.*

Transpiration is most active in moderately dry weather with good sunlight. Under such conditions the guard-cells drawing a good supply of sap become turgid, and the stoma is widened (Fig. 74) so that vapour escapes freely. In very dry weather the guard-cells lose their turgidity and become flaccid and flat till their free margins come in contact and close the stoma. In this way excessive transpiration and consequent withering are prevented.

The removal of water from the upper regions of the plant by evaporation causes a reduction of pressure in the wood-vessels. This draws up the sap from the lower parts so that transpiration aids the root-pressure in the ascent of the sap.

Absorption by the root thus supplies the parenchyma of the leaf with all the necessary elements except carbon. The latter is obtained by the leaf from the CO_2 of the air which enters the intercellular spaces through the stomata. The CO_2 is taken up by the water on the surface of the cells, and the H_2CO_3 so formed diffuses into the cells. From these simple materials the cells of the leaf synthesise carbohydrates and probably also complex nitrogenous compounds.

The assimilation of carbon in the presence of chlorophyll and sunlight is called *photosynthesis*. It has been shown in the chapter on Spirogyra that chlorophyll absorbs certain rays from sunlight, especially those in the red region of the spectrum, thus furnishing the plant with the energy necessary for splitting up such stable chemical compounds as CO_2 and water and building up carbohydrates. The details of the chemical changes occurring in this process are not known.

The ultimate result is the liberation of oxygen and the formation of grape-sugar as expressed by the equation.

$$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6\ O_2$$

Sugar is the first carbohydrate formed by the plant, though starch is the first visible product. As more sugar is produced than is required for the immediate needs of the plant, the surplus is stored up as starch in the chloroplasts. This storage is only temporary; during the night when carbon assimilation stops, the starch is converted into sugar, and the latter is conveyed to different parts of the plant.

It can be shown by experiments that both chlorophyll and light are essential for carbon assimilation. If a seedling be grown with its root immersed in a jar of Knop's solution from which iron has been completely excluded, there is no development of chlorophyll and the plant appears colourless or yellow. Expose such a plant to bright sunlight for some hours, then treat the parenchyma of the leaf with iodine solution to see if starch is present. You will find no starch has been formed. This experiment shows that chlorophyll is essential for carbon assimilation. Now take a green plant which has been kept in a dark room until starch has disappeared from the chloroplasts and wrap a sheet of tin-foil round one half of a leaf. Place the plant in bright sunlight for some hours, and look for starch in different parts of the leaf. You will find it in the chloroplasts of the part exposed to light, but none in those of the region covered by the tin-foil. Sunlight is, therefore, indispensable for carbon assimilation.

The process of elaboration of complex nitrogenous substances such as proteids and lecithins, which are always present in living protoplasm, is even more obscure. It is not certain in what particular region they are formed, what series of chemical changes occur in the process, and what external conditions influence it.

The synthesis of nitrogenous substances probably takes place in the parenchyma of the leaf, though some believe that the bast tissues, especially the sieve-tubes, are the seat of this process since accumulations of proteids are found in the neighbourhood of the sieve-plates. The question whether chlorophyll and sunlight directly or indirectly influence the process cannot be settled until we possess some definite knowledge of the chemical interactions which occur in the synthesis of proteids by plants. One fact which the student of elementary biology should remember is that all green plants, with a few exceptions, obtain the nitrogen of the proteids from simple inorganic nitrates.

The sap containing the proteids and sugar which have been manufactured in the leaf descends through the bast to the stem, roots or wherever it may be required. A portion of these substances is used as food by the protoplasm, and supplies the energy required for life, growth and reproduction. The remainder is stored up in insoluble forms such as starch and proteid grains in the stem, rhizome or root for subsequent use by the plant, and in the cotyledons or endosperm of seeds for nourishing the growing embryo.

RESPIRATION.

In plants as well as in animals respiration signifies a continuous slow combustion of the protoplasm all over the

body. The oxygen of the air combines with the carbon and hydrogen of the tissues. As a result carbon dioxide, water and energy, chiefly in the form of heat, are produced.

The student is apt to overlook the fact that all the living tissues of the body are the seat of respiration. It is a function of protoplasm to respire. The respiratory organs of higher animals are simply the means for taking up oxygen from the air or water and getting rid of carbon dioxide. The leaves of plants are well adapted for a similar purpose in virtue of the numerous stomata which admit air into the intercellular spaces of the spongy mesophyll. From these spaces the oxygen passes through the cell-walls in solution into the interior of the cells, and is distributed to the protoplasm in all parts of the plant. Stomata and other openings are scattered over the surface of the stem and branches, and lead into intercellular spaces in the cortex. These also admit air for respiration.

During daytime the respiration of green plants is masked by the process of carbon assimilation, as the plant gives off oxygen and little or no carbon dioxide. At night, when the plant is no longer assimilating carbon, oxygen is absorbed and carbon dioxide is given off so that it is evident respiration is going on.

To demonstrate these facts place a plant under an inverted jar provided with an opening on two sides (Fig. 114). Connect the jar on one side with a U-tube containing fragments of caustic potash, and on the other with a bottle containing some lime-water, or better, baryta-water as shown in the diagram. A slow continuous current of air is drawn in

the direction of the arrows by means of a suction apparatus so that the air passes successively through the U-tube and the jar, and finally bubbles through the baryta-water. The latter becomes turbid in the presence of carbon dioxide. The caustic potash deprives the air of the carbon dioxide originally present in it. Therefore if the baryta-water becomes turbid it must be due to carbon dioxide liberated by the plant.

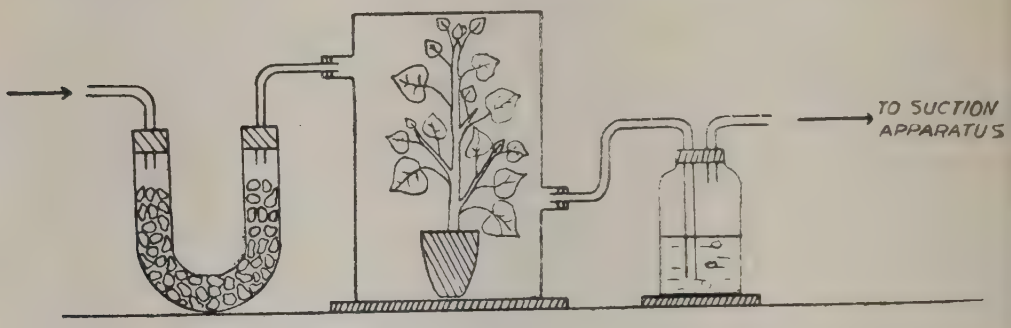

Fig. 114.

The first experiment is carried out with the apparatus exposed to bright sunlight. You will find the baryta-water remains clear. In this case respiration is still going on but, since photosynthesis is in progress, the plant uses up all the carbon dioxide it produces. Now repeat the experiment after covering the jar with a piece of black cloth in order to keep the plant in darkness. The baryta-warer will be seen to become turbid after a time. The explanation is that carbon assimilation is at a standstill owing to the absence of sunlight, and the carbon dioxide resulting from respiration is set free.

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Fig. 115.—*The Male (R. temporaria).* The right vocal sac slightly distended, as seen before the

THE FROG.

Frogs belong to the large group of animals known as Vertebrata, animals possessing a vertebral column consisting of a series of ring-like bones which together form a protective canal for the spinal cord. Vertebrata are divided into five classes : Fishes, Amphibia, Reptiles, Birds and Mammals. Frogs belong to the class Amphibia, which literally signifies " both lives," from the fact that frogs, like the rest of the members of this class, commence their lives as little fish-like creatures, breathing by gills adapted for aquatic life ; later they develop lungs, thus becoming potential land animals. This characteristic in their life-history and the absence of any cutaneous appendages like scales, feathers, hairs or nails, serve to place frogs under the class Amphibia and to distinguish them from the remaining four classes of Vertebrata.

In Bombay much the commonest species is *Rana tigrina*, a fortunate circumstance as its large size and fairly wide distribution make it convenient for dissection. The student will occasionally come across frog-like individual devoid of teeth. This may belong to a rare family of frogs, but it will more probably be a toad. The fact of its being a toad can be confirmed by the wrinkled skin, the presence of wart-like prominences on the surface and its sluggish crawling movements, while dissection will show that the two epicoracoids overlap each other.

Almost every marsh, pond, pool or tank of stagnant water has its small community of frogs. The young forms or tadpoles are purely aquatic and live on a vegetable diet; the adult can live both on land and in water and feeds on insects, small aquatic animals and worms which are flicked into the mouth by suddenly protruding the large viscid tongue and retracting it with equal suddenness. During periods of extreme cold or drought frogs retire under the mud and remain buried there, often huddled together in large numbers, till more favourable conditions of weather supervene. This is known as *hibernation* during which the vital functions are reduced to a minimum.

EXTERNAL APPEARANCE.

When the animal is in the sitting posture its back appears humped; but this is only apparent, for the vertebral column is straight and the prominence is formed by the peculiar mode of attachment of the pelvic girdle to the vertebral column.

The head gradually merges into the trunk as there is no intervening neck. Hence the form of the body is very well adapted to swimming. The tail is absent in the adult frog. The fore-limb is made up of an *arm*, *fore-arm* and *hand* with four digits which correspond to the index, middle, ring and little fingers of man. The pollex, or thumb, is suppressed, and is represented only by the small metacarpal bone which can be felt under the skin on the radial side of the hand. Note the flexion at the elbows making the animal appear bandy-legged. The hind-limb is divided into the *thigh*, *leg* and *foot* with five toes webbed nearly to the end. The student should note the great length of the part corresponding to

the ankle in man. This gives the appearance of an additional segment in the limb. Length of foot is characteristic of many animals capable of powerful leaping, *e.g.*, rabbits, kangaroos, jerboas, etc. The webbed toes make the animal an admirable swimmer. There are no claws or nails on either the fingers or the toes. At the base of the hallux there is a small prominence known as the *calcar*. This is formed by a small bony spur which can be felt under the skin. A fringe of skin runs up the limb for about an inch from the region of the calcar.

The skin is moist and slippery owing to the thin mucus secreted by numerous glands. The skin is an important respiratory organ in frogs, the moisture and great vascularity of the skin enabling an interchange of gases to take place between the atmosphere and the blood circulating in the minute capillaries of the skin. The ventral surface is always of a lighter colour than the dorsal. The males in *R. tigrina* are usually of a darker shade than females. The dorsal surface is mottled with dark spots of varying size.

The student will have noticed the great prominence of the eyes. There is no bony floor to the orbit, and the animal can protrude and retract the eye-balls at will. This compensates for the absence of a neck. If the mouth is opened it will be seen that retraction of the eye-balls causes a bulging in the roof of the mouth. The upper lid has very little motility. Touch the cornea with your finger, and you will notice that the upper lid descends very slightly, the eye-ball is retracted and rolled upward to some extent, while the lower lid consisting of a translucent membrane, moves upward till its free golden-tinted margin disappears under the edge of the upper lid. A little below and behind the eyes

are two nearly circular smooth patches. These are the *tympanic membranes*. The auricle and external auditory meatus of Man are not represented in the frog. Between the eyes in the mid-dorsal line is a small white spot about the size of a pin-head. This is known as the *brow-spot* and is believed to be the vestige of a median eye. In the male of *R. tigrina* loose folds of skin will be seen on each side of the throat a little below the articulation of the jaws. These allow the expansion of the subjacent vocal sacs, the black colour of which can be seen through the thin skin of this region. When air is forced out of the vocal sacs it passes through the glottis and sets up vibrations of the vocal cords, thus producing the familiar croaking sound which fills the night air during the courting season.

Of external openings there are only two in the median line, namely, the *mouth* and *cloacal aperture*. Note the great width of the mouth compared with the size of the body. The cloacal aperture lies near the posterior end of the body on its dorsal aspect. The nostrils or *anterior nares*, are paired apertures lying a little behind the tip of the snout. They lead into the nasal chambers. In the living animal the nostrils will be seen to open and close as the floor of the mouth is depressed and raised respectively. This is an important factor in the mechanism of respiration.

Grasp the living animal firmly round the lower part of the abdomen ; the pulsation of the posterior pair of *lymph hearts* will then be seen on each side of the middle line a little in front of the cloacal aperture. The pulsation of the anterior pair cannot be seen without dissection as this pair lies deep under cover of the suprascapular bones.

The frog may be killed by enclosing it under a bell-jar with a piece of cotton wool soaked in chloroform. Another method which is more useful to the student of physiology, consists in destroying the brain and spinal cord. This process is known as "pithing." To do this put a towel on the back of the animal with the free edge lying a little anterior to the shoulder girdle. The ends should then be crossed under the ventral surface so as to enclose the fore-limbs. Now grasp the frog firmly with the left hand, the thumb resting on the shoulder girdle, the index finger across the throat just anterior to the fore limbs, the remaining fingers lying behind them. Next incise the skin with the point of a scalpel in the mid dorsal line starting just behind the eyes and proceeding slowly backward till the point suddenly dips into the interval between the skull and the atlas. Now rotate the blade through a right angle and make a short stab so as to sever the cord from the brain. Take a stout pin, two or three inches long and introduce it through the same interval *via* the foramen magnum into the interior of the skull. By moving the pin from side to side the brain substance will be broken up. Withdraw the needle and pass it backward into the neural canal and similarly destroy the spinal cord. A properly pithed frog will lie perfectly still with the muscles completely relaxed.

The student should now open the mouth and examine the buccal cavity. Note the close-set, slender, curved *maxillary teeth* all along the upper jaw. They grow from the gums and later become fixed to the subjacent bone. They are fragile and those that break off are constantly replaced by new growths from the gums. The frog has teeth also in the

roof of the mouth. These are called *vomerine teeth* from their connection with the vomer bones; they are arranged in two short rows which run obliquely backward and inward from the anterior and internal margin of the posterior nares. Note the bulging in the roof of the mouth caused by the eye-ball when retracted. Next note the large viscid *tongue*, fixed anteriorly and having a free bifid posterior end. By this arrangement the tongue can be thrown forward to a considerable distance to capture food. Just internal to and parallel with the maxillary teeth, is a fringe of mucous membrance with a free sharp margin. A cartilaginous plate can be felt embedded in the floor of the mouth. This is the body of the *hyoid*. In the male of *R. tigrina* there are three paired openings inside the mouth: (1) the *posterior nares* lying close in front of the vomerine teeth. They lead into the nasal chambers and a bristle passed through them will be seen to emerge through the anterior nares; (2) the *Eustachian recesses* lying on the roof of the mouth internal to the articulation of the jaws. They lead into the *tympanum* or *middle-ear*. A bristle passed through a perforation in the tympanic membrane will pass into the mouth through the Eustachian recess; (3) the *openings of the vocal sacs*, two slit-like apertures in the floor of the mouth lying a little in front of the articulation of the jaws. Introduce the end of a blow-pipe into one of them and inflate the sac. This pair of openings is absent in the female.

There are two median apertures inside the mouth, namely, the *glottis*, or opening of the respiratory passage, and the commencement of the œsophagus. The glottis lies in the floor of the mouth. Pull the tongue forward; a small spot

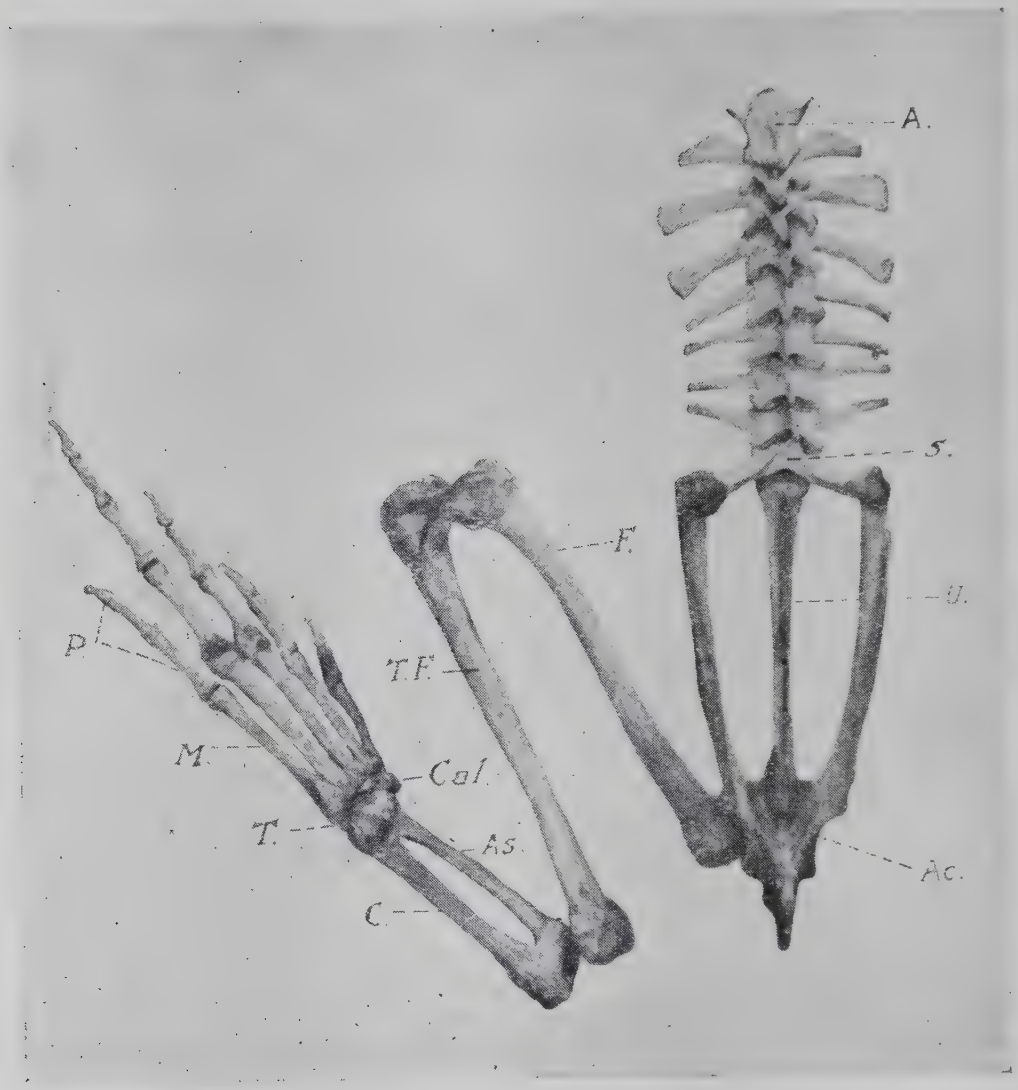

Fig. 121.—*The Vertebral Column and Hind Limb* (*R. tigrina*).

A.—Atlas.
Ac.—Acetabulum.
As.—Astragalus.
C.—Calcaneum.
Cal.—Calcar.
F.—Femur.
M.—Metatarsal bone.
P.—Phalanges.
S.—Sacral vertebra.
T.—Distal row of tarsal bones.
T. F.—Tibio-fibula.
U.—Urostyle.

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stiffened by the subjacent arytenoid cartilages, will then be made out with the finger. By pressing the end of a probe in the centre of this the glottis will come into view as a longitudinal slit-like aperture. A little beyond it lie two delicate white fringes. These are the *vocal cords*. The buccal cavity narrows posteriorly towards the puckered opening of the œsophagus.

THE SKELETON.

The term " skeleton " signifies all hard parts which serve to maintain the form of the body, to furnish attachment and leverage for muscles and to protect the soft parts. In Panulirus and the Cockroach the hard parts lie outside the soft, and constitute the exoskeleton, which is secreted by the epiderm ; any endoskeleton is merely an ingrowth of the exoskeleton. In the frog, however, there is no exoskeleton, and the cartilages and bones constitute an endoskeleton formed of mesoblastic tissue.

The skeleton can be divided into two parts : (1) the *axial* consisting of the skull, vertebral column and the hyoid apparatus, and (2) the *appendicular* consisting of the pectoral and pelvic girdles with the bones of the limbs.

Note that the skull is flattened dorso-ventrally. Note the large size of the orbits which are not provided with a bony floor.

To understand the structure of the adult skull it is essential for the student to bear in mind the manner in which it is developed.

The primitive skull as seen in the tadpole is entirely cartilaginous, but later on parts become calcified, parts

ossified, and parts fortified by the addition of *membrane bone*, a term applied to bones that develop in places where no pre-existing cartilage is formed.

The *chondro-cranium* or primitive brain-case is a cartilaginous tube in which are lodged the brain and the olfactory and auditory sense organs.* In the adult Frog, after the membrane bones have been picked off the surface of the primitive cranium, the cartilage is seen to be invaded in five situations by bone. The *girdle-bone* or *sphen-ethmoid* is formed by the ossification of the anterior half of the cartilaginous tube. The posterior wall of the cranium is ossified on each side to form the *ex-occipital* bones between which lies the *foramen magnum*, a large opening through which the spinal cord communicates with the brain. Each ex-occipital bears a rounded knob, the *occipital condyle*, by means of which the skull articulates with the atlas vertebra. The remaining ossifications in the chondro-cranium are the *pro-otic* bones situated dorsally on each side of its posterior region to roof over the auditory capsules. In the roof of the chondro-cranium will be seen a large opening, the *fontanelle*, which extends forward in the roof of the girdle-bone for about one-third of its length. From the posterior portion of the fontanelle, a membrane passes downward on each side as far as the opening for the second cranial nerve, forming the upper boundary of the opening.

In the Edible and in the Grass Frog there are three separate openings in the roof of the cranium, a median

* The second pair of sensory capsules, the optic, is not attached to the skull. It consists only of the fibrous tissue which forms the sclerotic or outer coat of the eye-ball.

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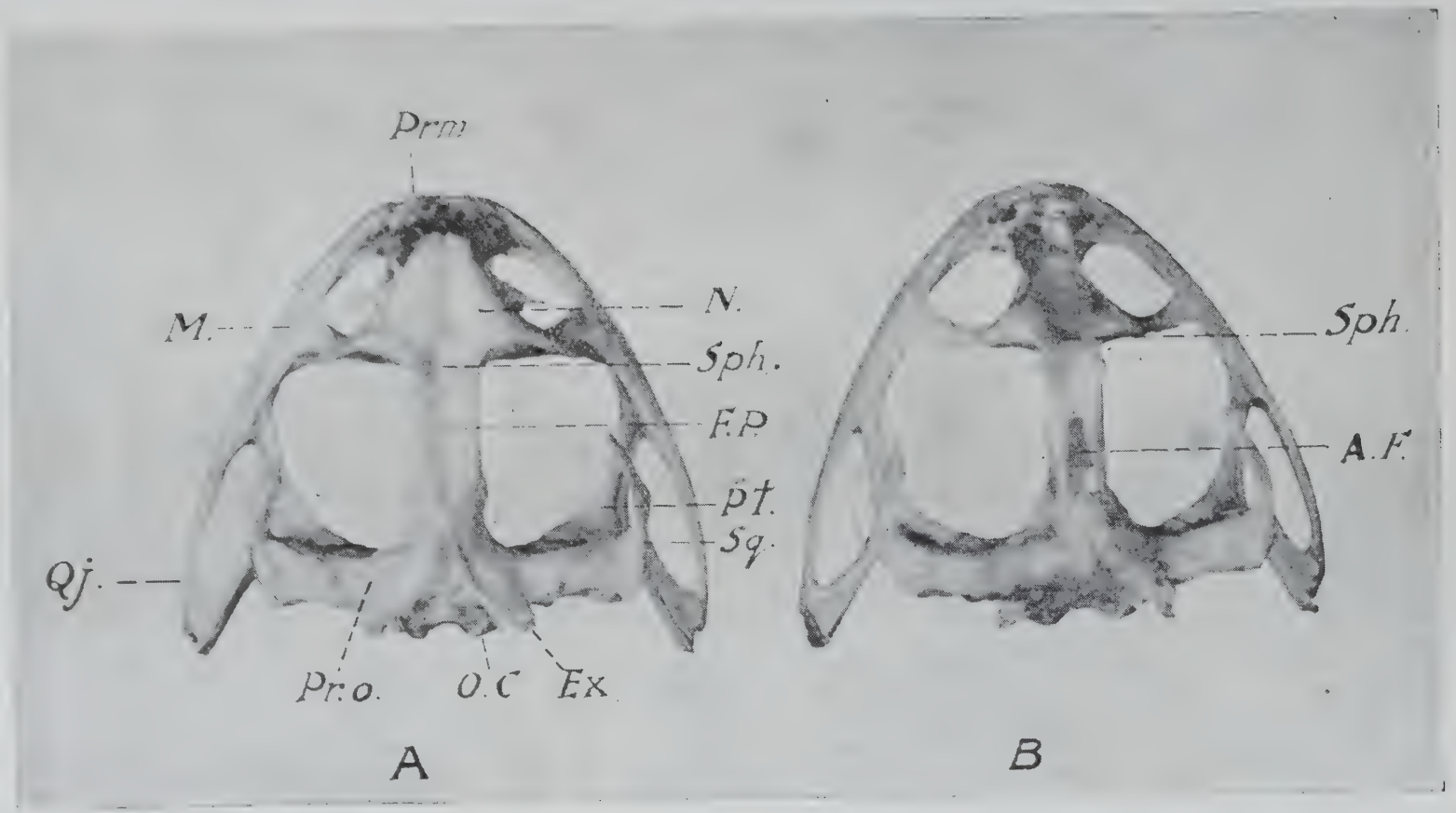

Fig. 116.—*The skull (R. tigrina) seen from the dorsal surface. In B. the fronto-parietal and nasal bones have been removed. This brings into view the fontanelle and the entire dorsal surface of the sphenethmoid.*

A. F.—Fontanelle.
Ex.—Exoccipital.
F. P.—Fronto-parietal.
M.—Maxilla.
N.—Nasal.
O. C.—Occipital condyle.
Prm.—Premaxilla.
Pr. O.—Pro-otic.
Pt.—Pterygoid.
Qj.—Quadrato-jugal.
Sph.—Sphenethmoid.
Sq.—Squamosal.

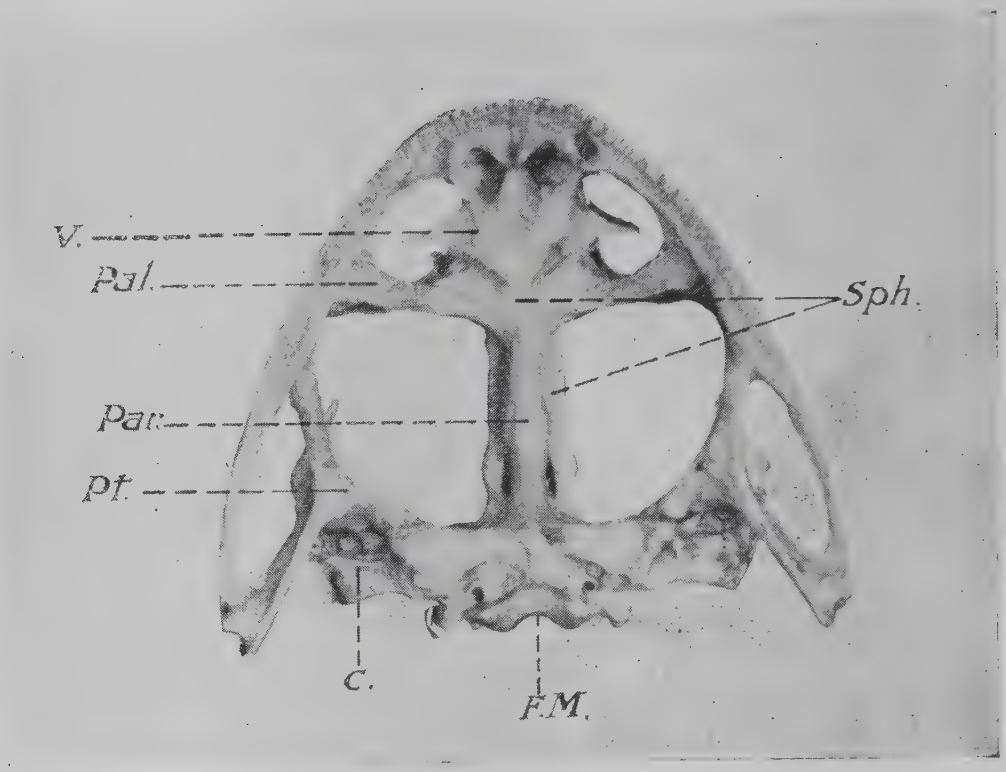

Fig. 117.—*The Skull* (*R. tigrina*) *seen from the ventral surface.*

C.—Columella.
F. M.—Foramen magnum.
Pal.—Palatine.
Par.—Parasphenoid.
Pt.—Pterygoid.
Sph.—Sphenethmoid.
V.—Vomer.

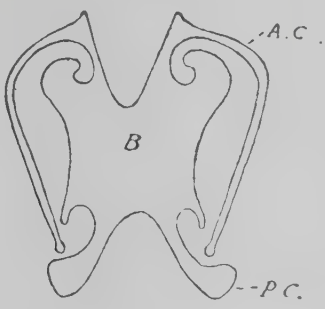

Fig. 118.—*The Hyoid* (*R. tigrina.*)

A. C.—Anterior cornu.
B.—Body of the hyoid.
P. C.—Posterior cornu.

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anterior, and two lateral *posterior fontanelles* corresponding to the upper part of the membrane found in *R. tigrina*.

In front of the exoccipitals, overlying the roof of the cartilaginous cranium, is a pair of elongated membrane bones, the *frontoparietals*, which meet and unite in the middle line. In front of the fronto-parietals, separated from them by a diamond-shaped area, are the nasals. Remove the nasals and fronto-parietals. The diamond-shaped area is now seen to be only a small part of the girdle-bone. The anterior part of the girdle-bone is divided into right and left compartments in which lie the olfactory sacs. Much of the lateral portions of the bone can be seen without dissection, but only a small part of its roof is seen in the diamond-shaped space described above. Ventrally it is also concealed to a great extent by another membrane bone, the dagger-shaped *parasphenoid*.

The cartilage of the olfactory capsules largely persists as such. Each capsule is, however, strengthened by two membrane bones—dorsally by the *nasal*, which is triangular, and ventrally by the *vomer*, which is triradiate and bears a row of teeth along its posterior margin.

The upper jaw originally consisted of two symmetrical rods of cartilage. These are united with each other anteriorly so as to form an arch which is attached to the cranium in front and behind. The posterior part of each rod is called the *quadrate* cartilage which serves to connect the lower jaw with the skull ; hence the name *suspensorium* is often given to it. Only a small part of it can be seen in the adult skull. It is fortified on its dorsal surface by the handle of a hammer-shaped membrane bone, the *squamosal*. The anterior part of each rod is called the *palato-pterygoid* car-

tilage. It is bent inward to be attached to the anterior end of the cranium. In the adult it is covered by two membrane bones seen on the ventral aspect of the skull, namely, the *palatine*, which is slender and horizontal, and the *pterygoid*, which is triradiate. Remove the palatine and the anterior process of the pterygoid on one side. The subjacent cartilage will be seen to be ossified. The posterior process of the pterygoid covers the ventral surface of the quadrate cartilage, while the inner process joins the auditory capsule. Other membrane bones of the upper jaw are from before backwards the *premaxilla*, *maxilla* and "*quadrato-jugal*," the first two of which bear teeth.

The primitive lower-jaw consists on each side of the rod like *Meckel's cartilage*. These are united with each other anteriorly, while posteriorly they articulate with the quadrate cartilage. In the adult skull the cartilage is not seen as its anterior part becomes ossified to form the *mentomeckelian* while the rest becomes ensheathed by two membrane bones, the *dentary* on the anterior part of the outer surface, and the *angulosplenial* which lies further back and covers the inner and lower surfaces.

The hyoid apparatus is formed chiefly of cartilage. It consists of the *columella* and the *body of the hyoid* with a pair of *anterior cornua* and a pair of a *posterior cornua*. The columella is a delicate rod attached at one end to the inner surface of the tympanic membrane and at the other to the *fenestra ovalis*, an oval opening in the internal ear.

The body of the hyoid is a thin, shield-shaped plate of cartilage which can be felt lying in the floor of the mouth. The anterior cornua are two long slender strips of cartilage attached above to the auditory capsules whence they pass, first

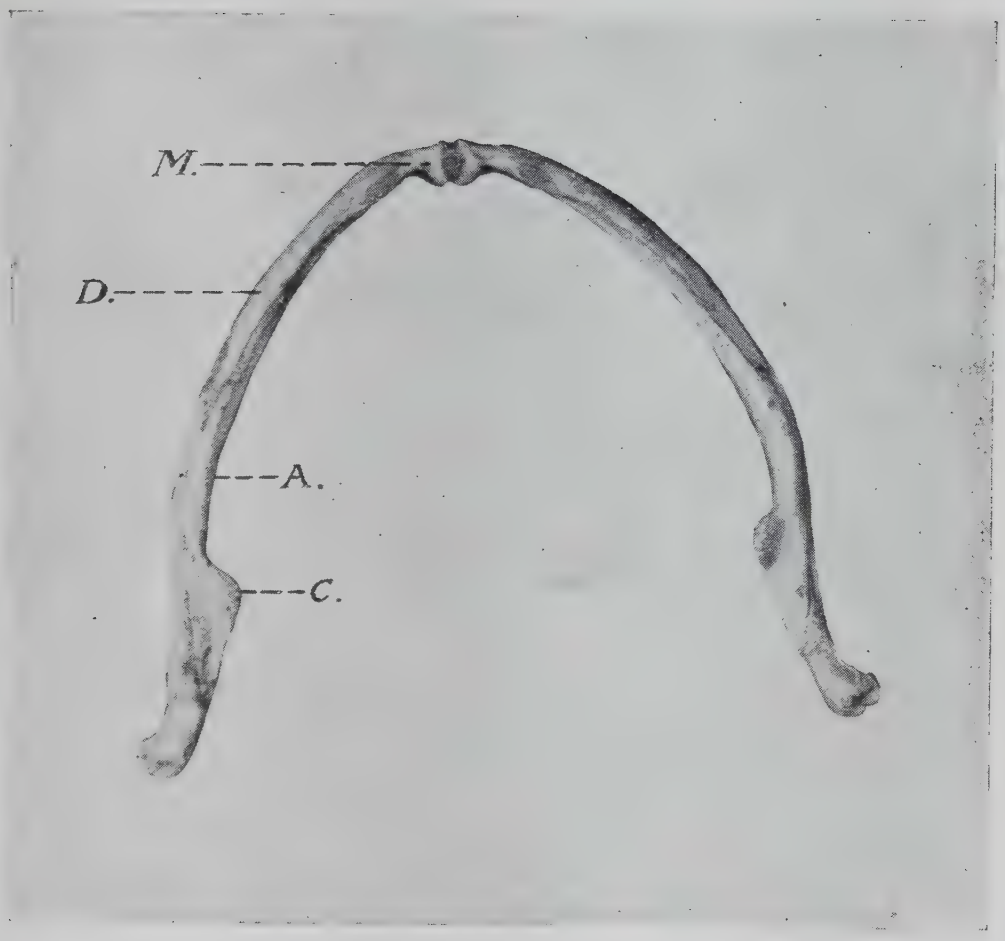

Fig. 119.—*The Lower Jaw* (*R. tigrina*) *seen from the dorsal surface.*

A.—Angulosplenial.
C.—Coronary process.
D.—Dentary.
M.—Mentomeckelian.

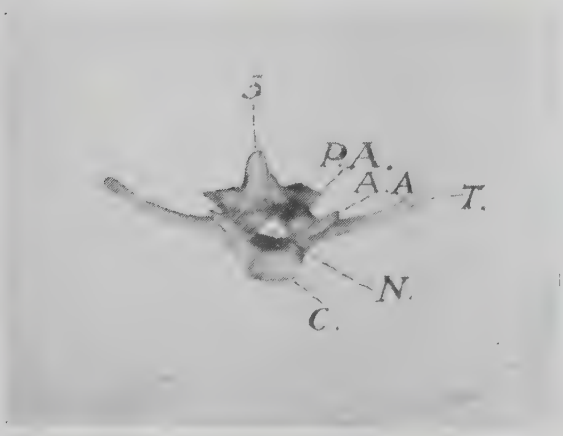

Fig. 120.—*The Fifth Vertebra* (*R. tigrina*) *seen from the front.*

A. A.—Anterior articular process.
C.—Centrum.
N.—Neural Canal.
P. A.—Posterior articular process.
S.—Spinous process.
T.—Transverse process.

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backward and downward, then forward to join the outer anterior angles of the body of the hyoid. The posterior cornua are two club-shaped bony processes projecting backward from the posterior margin of the body of the hyoid.

The vertebral column consists of ten bones: nine vertebræ and the urostyle. The student will notice that the column cannot be divided into distinct regions as is the case in the vertebral column of the rabbit. In the rabbit the presence of the axis vertebra renders rotation of the head possible. In the frog this bone is absent, so rotation cannot occur. In the rabbit, the centrum or body of the vertebra is capped at each end by a thin disc of bone, the *epiphysis*. The centra of the vertebræ of the frog have no epiphyses.

The second to the seventh vertebræ are all of the same type. Each vertebra is of an irregular ring shape, the whole series forming a bony tube for the protection of the spinal cord. The floor of the tube is formed by the thick disc-like, ventral portion of each ring, called the *centrum* or *body*. The remainder of the circumference of the ring forms the *neural arch*. The posterior end of the centrum is convex, the anterior concave. Hence the centrum is said to be *procœlous*. The convexity of one centrum fits into the concavity of the one behind, the union being effected by a disc of very tough cartilage called the *intervertebral disc*. The *spinous process* projects upward and backward from the neural arch. The *transverse processes* project outward from the arch. Note that both the anterior and posterior borders of the arch possess two small processes with facets. These are the *anterior* and *posterior articular processes*. The anterior processes have their facets on the dorsal surface, while those

of the posterior are on the ventral surface. By means of these facets the posterior articular processes of one vertebra articulate with the anterior processes of the vertebra immediately behind, and the bones are hinged together so as to allow slight movement. The student will notice a small notch on the anterior and posterior aspects of each arch laterally. When the vertebræ are linked together the adjacent notches form complete holes known as the *intervertebral foramina*. Through these the nerves arising from the spinal cord pass out to their distribution.

The first, eighth and ninth vertebræ present certain modifications from the typical structure. The first or *atlas* vertebra has neither anterior articular nor transverse processes, and its centrum is ill-defined. Anteriorly it has two large concave facets which articulate with the occipital condyles of the skull. The eighth vertebra has a centrum which is concave at both ends and is therefore said to be *amphicœlous*. The transverse processes of the ninth or *sacral vertebra* are very stout, and articulate with the pelvic girdle. Its centrum is *acœlous*, that is, neither surface is concave, the anterior being convex and the posterior possessing two small convex elevations.

The *urostyle* is a long rod-like bone bearing a thin longitudinal crest on its dorsal surface. The anterior end has two concave facets for articulation with the ninth vertebra. The neural canal is continued into its anterior end for about half an inch.

The student will notice the absence of ribs. The part which is played by the ribs and the muscles attached to them in the respiration of Man is performed in the frog by the

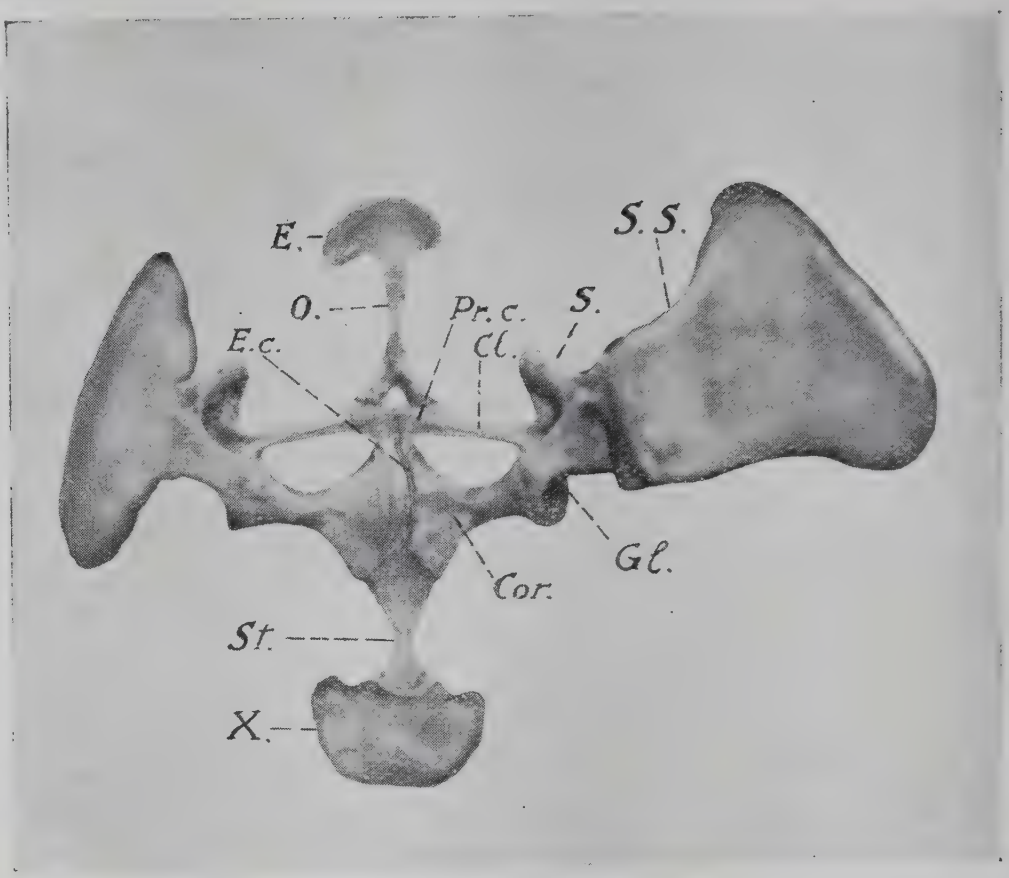

Fig 122.—*The Pectoral Girdle* (*R. tigrina*) *seen from the dorsal surface The left coracoid is seen overlapping the right dorsally.*

Cl.—Clavicle.
Cor.—Coracoid.
E.—Episternum.
E. C.—Epicoracoid.
Gl.—Glenoid cavity.
O.—Omosternum.
Pr. C.—Precoracoid.
S.—Scapula.
S. S.—Suprascapula.
St.—Sternum, or Mesosternum.
X.—Xiphisternum.

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" buccal force-pump " which we saw in action in the living animal.

The *shoulder girdle* is an inverted arch of bone and cartilage which, with the anterior vertebræ, forms a ring of skeleton for the protection of the heart and lungs and provides a firm base for the attachment of the fore-limbs.

It consists of a median sternal portion and right and left symmetrical lateral portions to which the limb is articulated. Each lateral portion bears on its posterior aspect a cup-shaped depression, the *glenoid cavity*, with which the head of the humerus articulates. Each lateral portion is divisible into two regions which meet at and enter into the formation of the glenoid cavity. That dorsal to the glenoid is the scapular region, that ventral is the coracoid.

The scapular region consists of (*a*) a flat plate of cartilage the *suprascapula*. Its narrower external end where it joins the scapula is calcified, *i.e.*, the cartilage is impregnated with deposits of lime salts, and is moreover covered dorsally by a thin sheet of bone, while the free margin consists of cartilage. The suprascapula is united to (*b*) the *scapula*, or shoulder blade proper, an elongated bony plate the proximal and of which forms half of the glenoid cavity.

In the coracoid region we have an anterior and a posterior segment separated by a semi-circular opening. The posterior and larger segment is the *coracoid*, a stout bone joining the scapula with the epicoracoid. Its outer end forms half of the glenoid cavity. The anterior segment is the *precoracoid*, a slender transverse rod of calcified cartilage which is united externally with the scapula and internally with the epicoracoid. A thin membrane bone, the *clavicle*, is attached

to the antero-dorsal surface of the precoracoid and is not easily distinguished from it.

The coracoids and precoracoids do not meet with their fellows of the opposite side in the middle line, but are linked together by two narrow strips of cartilage called the *epicoracoids*. In frogs the epicoracoids are united together by their mesial borders, but in toads they overlap each other. In *Rana tigrina* the inner ends of the coracoids are bevelled and in some individuals the convex median margin of the right slightly overlaps the left dorsally, while in others the left has a convex margin which overlaps the right.

The median sternal portion consists from before backwards of the *episternum*, a small disc of cartilage; the *omosternum*, a slender bony rod bifurcated posteriorly where it abuts on the clavicles; the *mesosternum*, a flattened rod of bone projecting backward from the coracoids; and the *xiphisternum*, a thin broad plate of cartilage.

The long bones of the limbs are all preformed in cartilage. In the elongated middle region or *shaft* the outer portion of the cartilage is replaced by a gradually thickening cylinder of bone formed by the ensheathing membrane or *periosteum*, while that in the centre disappears and is replaced by a fatty vascular tissue called the *marrow*. At the articular ends, lime salts are deposited within the cartilage, which persists on the surface, continues to grow and thereby adds to the length of the bone. The student will easily recognise these calcified caps covering the ends of the shaft in macerated long bones.

The proximal bone of the fore limb is called the *humerus*. It consists of the head or proximal end, the shaft and the

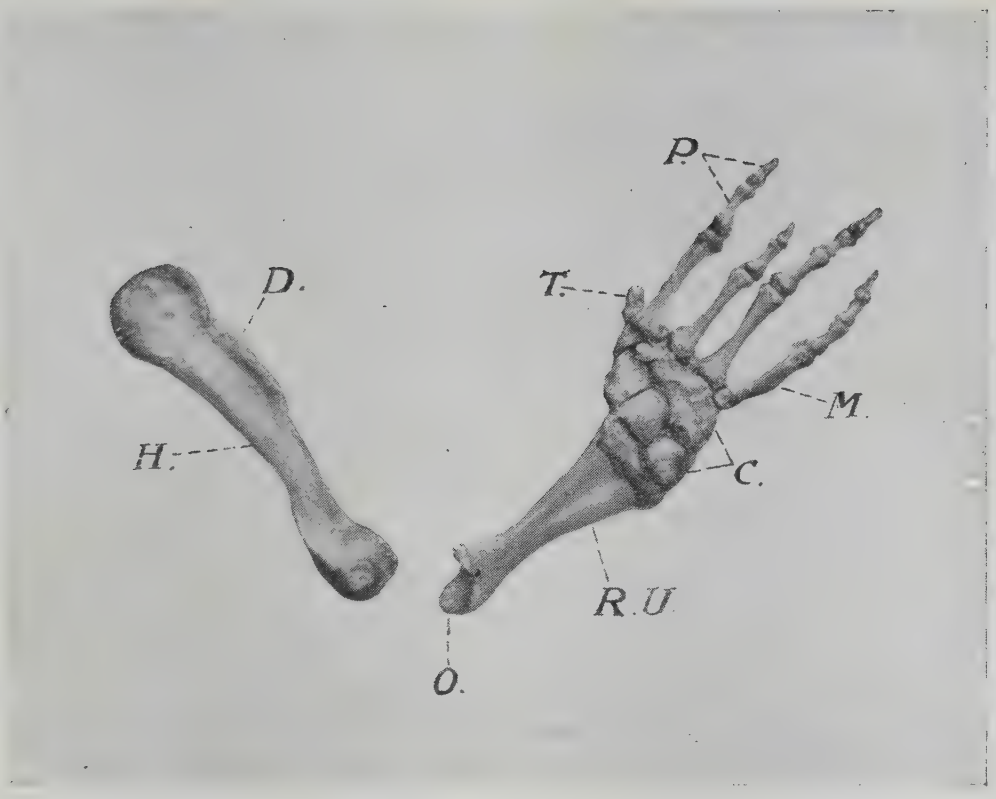

Fig. 123.—*The Fore-Limb* (*R. tigrina*).

C.—Carpus.
D.—Deltoid ridge.
H.—Humerus.
M.—Metacarpal bone.
O.—Olecranon process.
P.—Phalanges.
R. U.—Radio-ulna.
T.—Rudimentary metacarpal bone of the thumb.

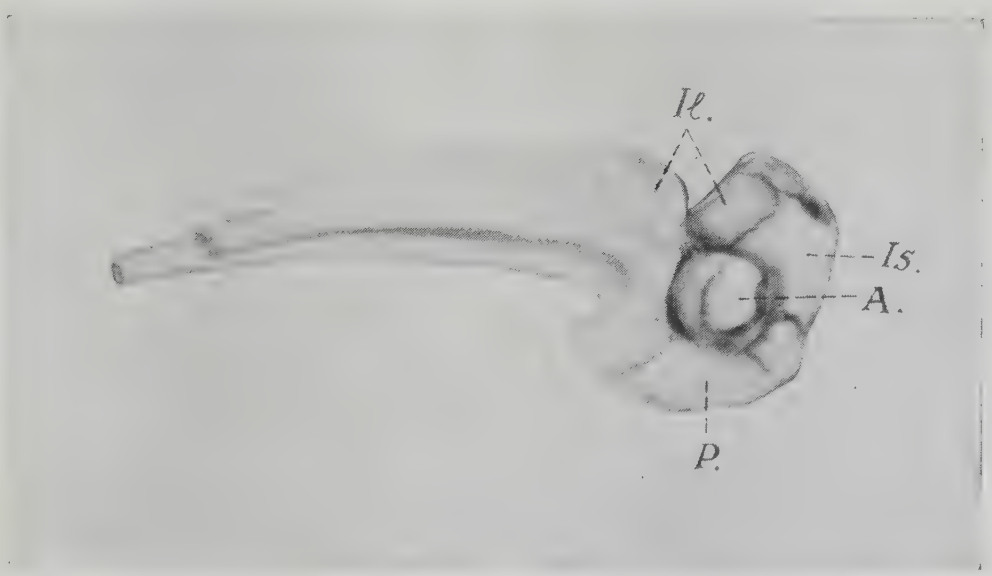

Fig. 124.—*The Pelvic Girdle* (*R. tigrina*) *seen from the side.*

A.—Acetabulum.
Il.—Ilium.
Is.—Ischium.
P.—Pubis.

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distal end. The head is large and articulates with the glenoid cavity. A prominent *deltoid ridge* runs along the upper half of the anterior surface of the shaft. The distal extremity bears a nearly globular articular surface. The ridges on either side of this are known as the *condylar ridges*.

In the fore-arm there are two bones fused together constituting the *radio-ulna*. The union is almost complete at the proximal end but distally, a groove marks out an anterior bone, the radius, from a posterior, the ulna. The proximal end has a concave articular surface with a projecting *olecranon* process.

In the wrist or carpus, there are six small *carpal* bones. These are arranged in two rows of three each, the proximal row articulating with the radio-ulna and the distal with the metacarpal bones.

The hand contains four slender *metacarpal* bones. The *phalanges* form the framework of the fingers. The pollex or thumb is represented by a small metacarpal bone only.

The *pelvic girdle* consists of a single bone formed by the union of two lateral portions. In the tadpole it consists of two symmetrical halves which make a cartilaginous arch, forming with the spinal column a ring or girdle enclosing the posterior viscera. During development the arch becomes rotated backward till it is almost parallel with the spine as seen in the adult.

Each lateral portion is formed by three points of ossification in the cartilage of the tadpole. The three bones so formed are united with each other and with their fellows of

the opposite side in a median *symphysis*. As in the shoulder girdle, the lateral portion is divisible into two regions which meet at and enter into the formation of a cup-shaped articular cavity, the *acetabulum*. That dorsal to it is the iliac region, that ventral is the ischio-pubic. The *ilium* is an elongated, rod-like bone attached by its anterior end to the tip of the transverse process of the sacral vertebra. Along its dorsal surface runs a thin ridge, the *iliac crest*, which does not reach quite to the anterior end. Only the posterior portions of the two ilia are fused with each other. The *ischium* is the posterior bone. The *pubis* is roughly triangular and lies ventrally.

In the hind-limb the proximal bone is called the *femur*. It consists of a rounded head which articulates with the acetabulum, a slightly curved shaft, and an expanded distal end having an articular surface.

The leg contains two bones fused together forming the *tibio-fibula*. This is shown by the presence of grooves which are more marked in the upper and lower thirds of the shaft than in the middle. The proximal end is thicker than the distal.

The elongated ankle or tarsus contains two rows of *tarsal* bones. The proximal row consists of two bones fused together at the ends, namely, the thin curved *astragalus* and the stout *calcaneum*. The distal row consists of two small bones.

The foot contains five *metatarsal* bones. The framework of the digits is formed by the *phalanges*. A small bone forms a sort of spur or *calcar* internal to the hallux. It is believed to be the rudiment of a sixth toe.

DISSECTION.

Lay the chloroformed or pithed frog on its back on a deal board. Steady it by fixing the extended limbs by strong pins or brad-awls. Pinch up the skin in the middle line of the abdomen with forceps and nick it with a pair of scissors. Cut the skin to the posterior end of the body and forward to the level of the shoulders. It will be found that at this level the skin is adherent to the subjacent muscles. Cut the muscles as close to the skin as possible and prolong the skin incision forward. Again the skin will be found to be adherent to muscles at the level of the articulation of the jaws. Cut the muscles close to the skin and prolong the skin incision to the chin. It will then be seen that the skin is free from the underlying muscles except along certain lines so as to form large subcutaneous *lymph spaces*, moistened by a colourless watery fluid known as *lymph*.

Through the white translucent muscles the student will note the musculo-cutaneous vein forming a U-shaped loop as it passes from the skin through the muscles towards the heart. Avoid injuring this vessel. The anterior abdominal vein will be seen running along the middle line of the abdomen under cover of the muscles. Long white nerves will be seen coursing through the muscles on each side of the middle line. In the male of *R. tigrina* the black vocal sacs will be seen lying close to the articulation of the jaws. Note the xiphi-sternum embedded in the muscles.

Cut the muscular wall of the abdomen a little to one side of the middle line so as to avoid injuring the anterior abdominal vein. Carry the incision back to the posterior end of the abdomen, and forward till a thin membrane is seen

attached to the body-wall. Within this membrane the movements of the heart will be seen. A small tributary, the sternal vein, is seen to come from the region of the sternum to join the anterior abdominal vein which here recedes from the body-wall. Gently grasp the anterior abdominal vein with the tips of the index finger and thumb, and with the point of a scalpel cut the tissue uniting the vein to the body-wall. By gentle traction on the vein the tissue can easily be torn and the vein separated from the muscles up to the posterior end of the abdomen.

Next pick up the muscles covering the clavicle and coracoid bones with the forceps, just a little to one side of the middle line and raise them with a scalpel so as to expose these bones. Proceed slowly and with care till you see a small vein emerging from the muscles and passing through the interval between the bones. This vein should not be injured. Stop when it comes into sight. Similarly, raise the muscles from the bones of the other side. Next cut the clavicles and coracoids just to the mesial side of the vein. Use only the extreme end of the bone-pliers so as to avoid injuring the deeper structures. Now pick up the xiphisternum and dissect out the entire "sternum" by cutting the soft parts attached to it as close to the cartilages and bones as possible. Remove the pins fastening the fore-limbs. By pulling the latter further apart a better view of the internal organs will be obtained.

The large body-cavity or *coelom* is thus opened up. In mammals like the rabbit and man, the coelom is divided by a muscular partition or *diaphragm* into two main cavities, the *thorax* and *abdomen*, lined respectively, by the *pleura*

and *peritoneum.* As there is no such partition in the frog there is only one cavity lined by a continuous membrane called, respectively, the *pleuro-peritoneal cavity* and the *pleuro-peritoneum.*

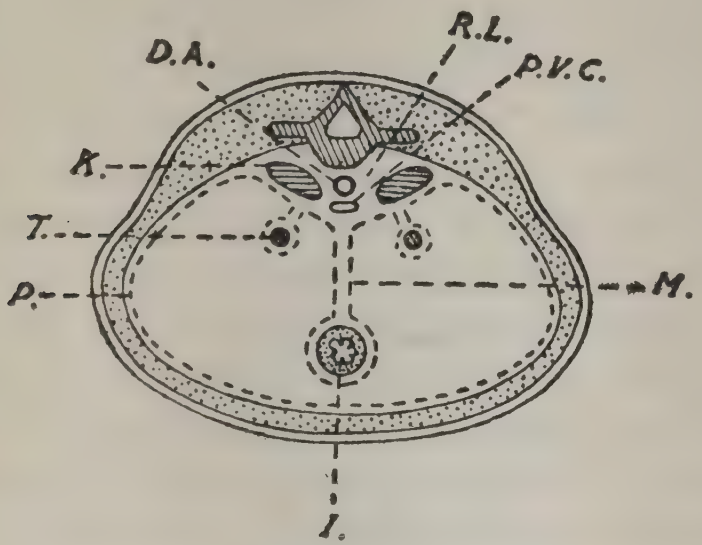

Fig. 125.—*Diagrammatic transverse section of the posterior part of the body of a male Frog.*

D. A.—Dorsal aorta.
I.—Loop of intestine invested by the pleuro-perioneum and suspended by the mesentery.
R. L.—Retroperitoneal lymph space.
K.—Kidney.
M.—Mesentery.
P.—Pleuro-peritoneum. (Dotted line).
P. V. C.—Posterior vena cava.
T.—Testis.

The stomach and intestines which appear to be lying in the pleuro-peritoneal cavity are in reality outside it as shown in the above diagram. If we can imagine the viscera to be pushed, as it were into this cavity lined by the elastic and distensile membrane, the latter will obviously be spread out on their surface. If a viscus is pushed still further into the cavity the membrane will come round on each side of it and form a

double layer called the *mesentery* by which the viscus will be suspended in the body-cavity. Between the two layers forming the mesentery lie the vessels and nerves going to or coming from the viscus. Note the numerous minute pigment dots in the pleuro-peritoneum. The glistening surface of the membrane is moistened by a thin clear serous fluid.

THE CIRCULATORY SYSTEM.

The student will do well to examine the circulatory system at this stage, for further manipulation and dissection is apt to injure the delicate veins and allow the blood, the colour of which renders them conspicuous, to run out.

The heart is surrounded by a thin, smooth, translucent membrane, the *pericardium*, which consists of two layers—the *visceral* layer which is closely adherent to the heart muscle, and the *parietal* which forms a loose sac investing the heart. These two layers are continuous with each other at the roots of the vessels. Slit up the parietal layer with small scissors. The pericardial sac thus opened is seen to contain a small amount of thin serous fluid which lubricates the surface.

Pick up the heart by catching the apex with forceps. It will be seen that each contraction starts in the blue sinus venosus, and spreads as a wave to the auricles, then to the ventricle and finally to the truncus arteriosus. This shows that the direction of the flow is from the veins to the heart and from the heart to the arteries.

THE VEINS.

The venous system consists of the systemic veins, the hepatic portal, renal portal and pulmonary systems. The

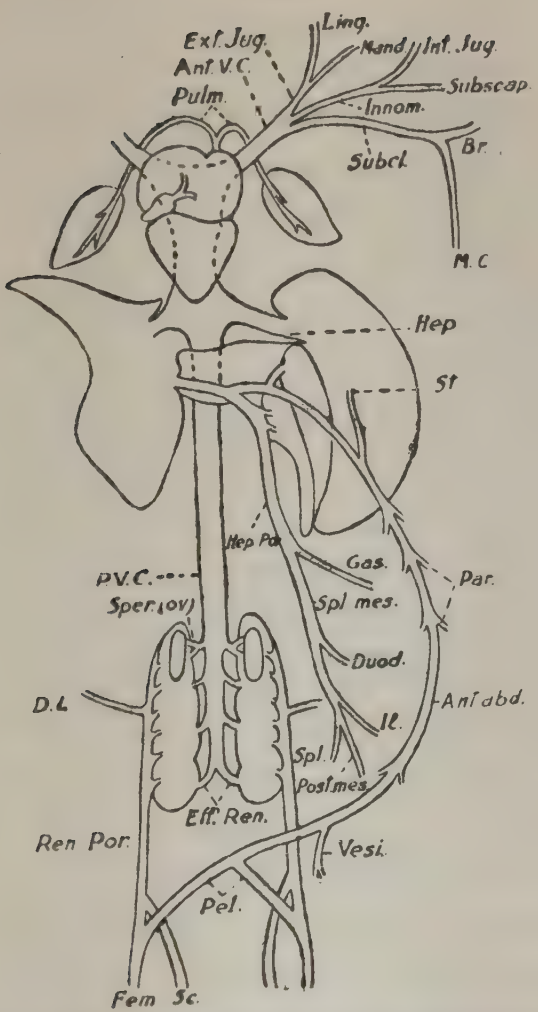

Fig. 126.—*Diagram of the venous system (R. tigrina) seen from the ventral aspect. The anterior abdominal vein is pulled over to the left.*

Ant. abd.—Anterior abdominal vein.
Ant. V. C. Anterior vena cava.
Br.—Brachial vein.
Duod.—Duodenal vein.
D. L.—Dorso-lumbar vein.
Eff. Ren.—Efferent renal veins.
Ext. Jug.—External jugular vein.
Fem.—Femoral vein.
Gas.—Gastric vein.
Hep.—Hepatic vein.
Hep. Por.—Hepatic portal vein.
Il.—Ileal vein (from the small intestine).
Innom.—Innominate vein.
Int. Jug.—Internal jugular vein.
Ling.—Lingual vein.
M.-C.—Musculo-cutaneous vein.
Mand.—Mandibular vein.
Par.—Parietal veins.
Pel.—Pelvic veins.
Post. mes.—Posterior mesenteric vein (from the large intestine).
Pulm.—Pulmonary veins.
P. V. C.—Posterior vena cava.
Ren. Por.—Renal Portal vein.
Sc.—Sciatic vein.
Sper. (Ov.)—Spermatic vein (ovarian in female).
Spl.—Splenic vein.
Spl.-mes.—Spleno-mesenteric vein.
St.—Sternal vein.
Subcl.—Subclavian vein.
Subscap.—Subscapular vein.
Vesi.—Vesical vein.

systemic veins consist of the right and left *anterior venæ cavæ* and the *posterior vena cava* with their tributaries. On lifting the heart by the apex the three caval veins will be seen to open into the *sinus venosus*.

The posterior vena cava is formed by the union of several small veins coming from the kidneys called the *efferent renal* veins. Slit up the pleuro-peritoneum midway between the kidneys with small scissors and trace the vena cava towards the heart. As it proceeds forward it is joined by a few small veins, the *spermatic* or *ovarian*, coming from the testes or ovaries as the case may be. It then passes behind the liver and, just before its termination in the sinus venosus, receives the two large efferent *hepatic* veins one from each lobe of the liver. These veins can be readily seen on lifting the heart by the apex.

The student will find it more difficult to trace the tributaries of the anterior vena cava. They are the same on each side. Pick up the heart by the apex and turn it to one side so that the apex points to the corresponding shoulder. By doing this you will expose the anterior vena cava of the opposite side as it enters the sinus venosus. It is formed by the union of the *external jugular, innominate* and *subclavian* veins. These vessels lie ventrally to the main arteries springing from the truncus arteriosus and are somewhat obscured from view by the soft pigmented fatty tissue which lies in this region. In looking for them, carefully trace the tributaries of each from the periphery towards the heart. If the black tissue is in the way it should be removed. The external jugular is formed by the union of the *lingual* and *mandibular* veins. The lingual

vein will be easily seen as it passes straight backward from the tongue under cover of the muscles and the body of the hyoid. Cut out the muscles and also a portion of each anterior cornu of the hyoid near its commencement. The lingual artery will be seen on the ventral surface of the body of the hyoid, and the lingual vein on the dorsal. Separate both vessels from the cartilage, and remove the latter by cutting the soft tissues which hold it in place. The mandibular vein will be seen coming from the region of the articulation of the jaws. The innominate vein is formed by the union of the *internal jugular* and *subscapular* veins. The internal jugular lies somewhat deeply and requires the removal of a little muscular tissue for its demonstration as it emerges from the interior of the skull. It will be found at the bottom of a recess close to the articulation of the jaws. The subscapular vein lies posterior to the large brachial nerve and passes transversely inward from the region of the scapula. The subclavian vein is formed by the union of the *brachial* and *musculo-cutaneous* veins. The former should be looked for where it joins the musculo-cutaneous along the inner wall of the arm-pit. Expose it by cutting the skin and muscles on the posterior aspect of the arm. The musculo-cutaneous vein courses through the muscles of the anterior abdominal wall and should be exposed by separating the layers of muscles between which it lies.

The hepatic portal system is formed by the veins coming from the stomach, intestines and spleen. The term " portal " is applied to a system of veins that breaks up into capillaries before reaching the heart. Thus the *hepatic portal* vein breaks up into capillaries in the substance of the liver. It

is formed by the union of the *gastric* vein from the stomach with the *spleno-mesenteric* vein. The latter is formed by the union of veins from the large and small intestines and the *splenic* vein. After giving off branches which enter the under surface of the left median lobe of the liver the hepatic portal vein is joined by a communicating twig from the anterior abdominal vein, and finally the vessel enters the right lobe of the liver. For the dissection of the above veins spread out the mesentery extending between the stomach and the duodenum and peel off the layer covering the vessels. The hepatic portal vein will be seen as it traverses the lobules of the pancreas.

The *anterior abdominal* vein also belongs to the hepatic portal system for it divides into two branches one of which enters the left lateral lobe of the liver and breaks up into capillaries, while the other is the communicating twig mentioned above. The abdominal vein is formed by the union of the two *pelvic* veins. As it proceeds forward it is joined by the small *vesical* veins from the bladder, several *parietal* veins from the muscles of the anterior abdominal wall and the small *sternal* vein, already seen in an early part of the dissection, coming from the region of the sternum.

The renal portal system is so called because the renal portal vein breaks up into minute capillary vessels in the substance of the kidney. By tracing one of the pelvic veins backward it will be seen to be one of the two terminal divisions of the *femoral* vein which returns the blood from the hind-limb. The other division of the femoral vein is called the *renal portal* which passes forward along the outer border of the kidney to which it gives off several *afferent renal* veins.

It receives two tributaries, namely, the *sciatic* and *dorso-lumbar*. It will be seen that all the blood from the hind-limbs of the frog has to pass through one or other of the portal systems before reaching the heart. Cut through the skin and muscles along the middle of the outer surface of the thigh, and lay bare the femoral vein and its bifurcation. Separate the pelvic veins from the subjacent muscles, and expose the sciatic, dorso-lumbar and renal portal veins by opening up the subvertebral lymph space.

The *pulmonary* veins will be seen on the inner surface of the lungs. The main vein of each side passes inward behind the sinus venosus. The two then unite and the single trunk enters the posterior wall of the left auricle. The student will find it difficult to trace the pulmonary veins in the course of an ordinary dissection.

While searching for the external jugular vein the student will notice two small rounded bodies of a reddish colour lying along the external jugular vein of each side. These are the thyroid glands.

THE ARTERIES.

The truncus arteriosus divides into the right and left trunks. The condition therefore differs from that seen in the adult rabbit in which only the left arterial trunk is present. Each trunk though externally it appears single, contains three separate channels corresponding to the three branches into which it divides. These branches are the anterior *carotid* arch, the middle *systemic* or *aortic* arch and the posterior *pulmo-cutaneous* arch.

To expose these arches and their main branches gently pull over the external jugular and innominate veins towards

the truncus arteriosus with small forceps, and with another pair pick up the combined trunk a little before its division into the three arches. Gentle traction on the vessel and a little clearing of the surrounding tissue with the point of a scalpel will bring the vessels into view.

The carotid arch divides into the *lingual* artery to the tongue and the *carotid* artery which supplies blood to the head and the brain. At the commencement of the carotid artery is a small oval enlargement, the *carotid plexus*, the spongy structure of which offers considerable resistance to the passage of blood through it. The student has already dissected the lingual artery. Separate it from any soft tissue to which it is still adherent. To expose the carotid artery trace it forward and outward, cutting the muscles which cover it, until it disappears under cover of the mucous membrane lining the roof of the mouth. Cut the membrane in the line of the vessel, and separate the latter from surrounding structures as far as the point where it enters the skull. The pulmo-cutaneous arch will be seen to divide at the level of the carotid plexus into the *pulmonary* artery, which runs along the outer surface of the lung and the delicate *cutaneous* artery, which proceeds backward, and piercing the muscles of the back, supplies blood to a large area of the skin on the dorsal surface.

To expose the systemic arch, cut out the soft parts lying between the subscapular and subclavian veins with small scissors without injuring the veins. Next raise the lung by the apex and pull it to the opposite side. A thin sheet of muscle which passes inward from the region of the shoulder to the œsophagus is now seen. This should be divided.

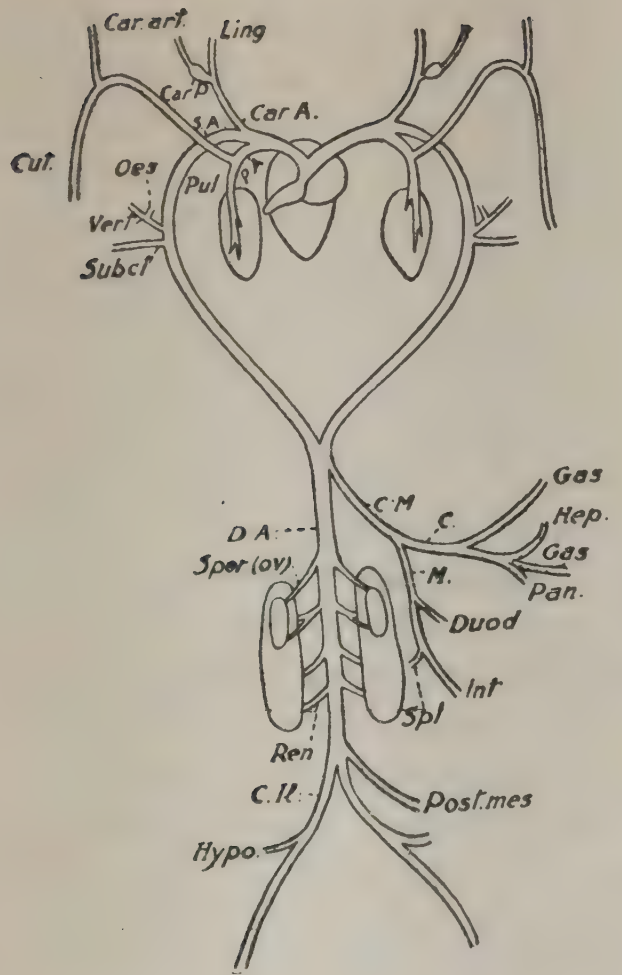

Fig. 127.—*Diagram of the arterial system* (*R. tigrina*).

C.—Coeliac artery.
C. II.—Common iliac artery.
C. M.—Coeliaco-mesenteric artery.
Car. A.—Carotid arch.
Car. art.—Carotid artery.
Car. P.—Carotid plexus.
Cut.—Cutaneous artery.
D. A.—Dorsal aorta.
Duod.—Duodenal artery.
Gas.—Gastric artery.
Hep.—Hepatic artery.
Hypo.—Hypogastric artery.
Int.—Intestinal artery.
Ling.—Lingual artery.
M.—Mesenteric artery.
Oes.—Oesophageal artery.
P. A.—Pulmo-cutaneous arch.
Pan.—Pancreatic artery.
Post. mes—Posterior mesenteric artery.
Pul.—Pulmonary artery.
Ren.—Renal arteries.
S. A.—Systemic arch.
Sper.—Spermatic artery (ovarian in female).
Spl.—Splenic artery.
Subcl.—Subclavian artery.
Vert.—Vertebral artery.

Also make a longitudinal incision in the pleuro-peritoneum in this region so as to open the large subvertebral lymph space lying dorsal to the membrane. On lifting the inner edge of the cut membrane the systemic arch will be seen as it curves backward to meet its fellow of the opposite side in the middle line. The entire arch from the heart to the commencement of the dorsal aorta should be thoroughly exposed and isolated by cutting the tissues which adhere to it, and removing them where possible. In this part of its course the arch gives off from its convex aspect the *vertebral* and *subclavian* branches which arise close together. The vertebral artery, after a short course, pierces the muscles of the back and supplies blood to them and to the spinal cord. The subclavian artery is longer and passes into the fore-limb. It lies in front of the large brachial nerve and should be traced outward into the arm. A small branch, the *œsophageal* artery, passes to the œsophagus from the vertebral artery.

The artery formed by the union of the two systemic arches is called the *dorsal aorta*. Its first branch is the *cœliaco-mesenteric* artery which arises at the very commencement of the dorsal aorta. Its origin can easily be seen by looking through the incision in the pleuro-peritoneum mentioned above. To trace its branches, draw the whole liver forward and keep it there by the pressure of the finger. Next draw the stomach and intestines well over to the left side. The artery will then be seen covered by the pleuro-peritoneum. By incising the latter in the course of the vessels, and not across them, the various branches can be made out. The cœliaco-mesenteric artery divides into

the *cœliac* and *mesenteric* arteries. The cœliac gives off the *hepatic* artery to the liver, the *gastric* artery to the stomach and the *pancreatic* artery to the pancreas. The mesenteric artery gives off the *duodenal* artery to the duodenum, *intestinal* artery supplying the small intestine and the upper part of the large intestine, and the *splenic artery* to the spleen. The lower part of the large intestine receives the *posterior mesenteric* artery a small vessel arising from the dorsal aorta just prior to its bifurcation.

Other branches of the dorsal aorta are the *spermatic* or *ovarian* arteries to the testes or ovaries and oviducts, and several *renal* arteries to each kidney.

Finally, the dorsal aorta ends by dividing into the two *common iliac* arteries. Each common iliac gives off a small *hypogastric* artery to the bladder. The common iliac artery then passes into the hind-limb and becomes the *sciatic* artery which runs in company with the sciatic nerve between the muscles on the dorsal aspect of the thigh.

THE HEART.

The heart consists of a series of chambers with muscular walls of varying thickness, namely, the *sinus venosus*, two *auricles*, one *ventricle* and the *truncus arteriosus*. It therefore differs from the heart of the rabbit in which we find two distinct ventricles but no sinus venosus or truncus arteriosus. Externally the auricles are marked off from the ventricle by the *auriculo-ventricular groove*.

If the heart is cut longitudinally after hardening, it will be seen that the sinus venosus opens into the right auricle by the *sinu-auricular aperture* which is provided with lipped

edges. In the left auricle there is a single aperture which is the opening of the vein formed by the union of the two

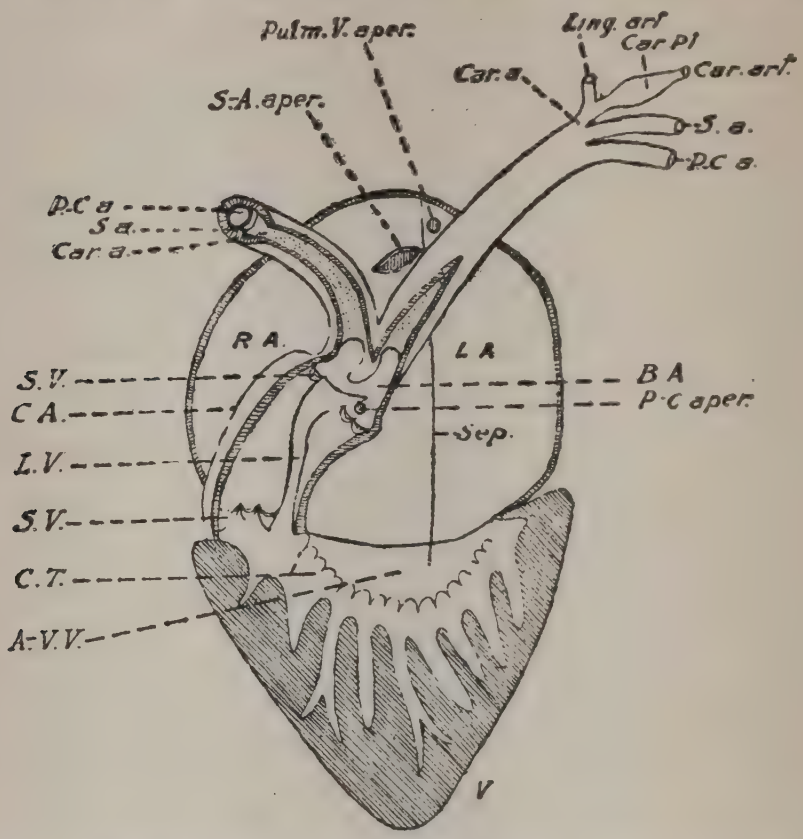

Fig. 128.—*Diagram of the heart (R. tigrina) dissected from the ventral surface.*

A.-V. V.—Auriculo-ventricular valve.
B. A.—Bulbus arteriosus.
C. A.—Conus arteriosus.
Car. a.—Carotid arch (laid open).
Car. art.—Carotid artery.
Car. Pl.—Carotid plexus.
C. T. —Chordæ tendineæ.
L. A.—Left auricle.
L. V.—Longitudinal valve.
Ling. art.—Lingual artery.
P. C. a.—Pulmocutaneous arch.
P.-C. aper.—Aperture of pulmocutaneous arches.
Pulm. V. aper.—Aperture of pulmonary vein.
R. A.—Right auricle.
S. a.—Systemic arch.
S. A. Aper.—Sinu-auricular aperture.
Sep.—Interauricular septum.
S. V.—Semilunar valves.
V.—Ventricle.

pulmonary veins. The two auricles are separated from each other by a thin partition, the *interauricular septum.* Its free posterior margin projects into and divides the auriculo-ventricular aperture into right and left portions.

The two auricles communicate with the ventricle by the single *auriculo-ventricular aperture* which is guarded by a valve consisting of two membranous flaps projecting into the ventricle. Note the delicate tendinous cords, the *chordae tendineae,* attached to the free edges of the flaps. This valve allows blood to flow from the auricles into the ventricle but prevents any flow in the reverse direction.

The cavity of the ventricle, excepting a small central portion, is traversed by numerous muscular strands. The truncus arteriosus arises from the right side of the ventricle and its opening is guarded by three *semilunar valves* which allow blood to pass from the ventricle into the truncus arteriosus but prevent its flowing back into the ventricle.

The truncus arteriosus is divisible into a proximal thick-walled part, the *conus arteriosus,* and a distal thin-walled part, the *bulbus arteriosus.* These regions can be readily made out in a hardened specimen. The conus arteriosus contains the large *longitudinal valve* which begins at the left margin of the aperture leading from the ventricle into the truncus arteriosus and passes obliquely forward and to the right. The longitudinal valve is attached dorsally while its ventral edge is free. At the anterior end of the conus there is another set of three *semilunar valves* guarding the opening leading into the bulbus arteriosus. They prevent back-flow into the conus. The bulbus arteriosus contains five apertures. One lies just beyond the semilunar valves a little to the left

of the anterior end of the longitudinal valve. It leads int the right and left pulmo-cutaneous arches. A tongue-lik process projects into the bulbus from the dorsal wall of i distal end. A septum passes from it on each side to join th outer wall and divides the lumen of the bulbus on each sid of the tongue into a double channel leading into the caroti and systemic arches.

THE MECHANISM OF CIRCULATION.

The pulmonary veins pour pure oxygenated blood int the left auricle. When the sinus venosus contracts th impure blood brought to it by the caval veins is force into the right auricle through the sinu-auricular apertur The two auricles contract simultaneously and empty the contents into the ventricle through the auriculo-ventr cular aperture. Hence the left portion of the ventricula cavity contains pure blood from the left auricle, the righ portion contains impure blood from the right auricle, whi between the two there will be some mixed blood. As th opening of the truncus arteriosus lies on the right sid of the ventricle the impure blood is the first to enter th truncus arteriosus, the mixed blood will come next and lastl the pure blood.

When the conus contracts these three kinds of bloo pass into the bulbus in the same order.

Now the resistance to the flow of blood is the least i the pulmo-cutaneous vessels. This is due partly to thes arteries being shorter and partly to the lung capillarie being comparatively broader than those of the systemi and carotid vessel. Moreover, the capillaries of the lun

and skin are on surfaces exposed to the air, the pressure of which only they have to overcome. The greatest resisance is in the carotid artery owing to the presence of the carotid plexus, and the fact that the carotid vessels are enclosed in a bony chamber which permits very little expansion of the vessels. Hence the impure blood following the path of least resistance enters the orifice of the pulmo-cutaneous arches and is conveyed to the lungs and skin to replenish its store of oxygen and get rid of its carbon dioxide. The tone of the muscles having to be overcome opposes a certain resistance to the flow of blood in the systemic vessels which traverse them. As the pulmo-cutaneous vessels become full the resistance they offer goes on increasing till it becomes greater than that in the systemic vessels. At the same time the increasing tension in the conus pushes the longitudinal valve to the left so that its anterior end closes the pulmo-cutaneous opening. Therefore the mixed blood coming next enters the systemic arches and the lingual arteries. As these vessels become full their resistance will go on increasing till it exceeds that offered by the carotid arteries. Hence the pure blood coming last enters the carotid arteries so that the brain receives the purest blood.

THE BLOOD.

The blood of the frog consists of a colourless fluid *plasma* and two kinds of cells, the *red* and the *white blood corpuscles*. The red are large, oval, nucleated and contain the pigment, *hæmoglobin*, to which the blood owes its colour. The white are fewer in number, clear, transparent, nucleated and show

amœboid movements. As the blood circulates through th lungs and skin the hæmoglobin takes up oxygen which i then taken to the tissues. The nourishment absorbed fron the alimentary canal passes to the blood plasma which take it to the tissues. Hence the blood is the carrier of oxyge and food to the tissues. Moreover, the waste products o the tissues pass into the blood which takes them to the lungs kidneys and other excretory organs. The kidneys remov these products in a state of solution in the urine, while th lungs and skin eliminate the carbon dioxide.

THE LYMPHATIC SYSTEM.

This is also a part of the circulatory system. In th frog and rabbit the blood circulates in closed tubes, thu differing from Panulirus and insects in which the vessels open into spaces in the tissues. These tubes can be readily seen in the web of the foot with a low power of the microscope The blood therefore does not come into direct contact with the tissues. Exchange of gases takes place through the thin walls of the capillaries while nourishment is carried to the tissues by the exudation of the clear plasma through the capillary walls. This exuded plasma is known as *lymph* The waste products of tissues become dissolved in the lymph which finds its way into irregular channels called *lymphatic vessels* which ultimately open into the veins. The lymph is pumped into the veins by two pairs of *lymph hearts*. The anterior pair lies deeply embedded in the muscles between the transverse processes of the third and fourth vertebræ. A special dissection on a recently killed frog is necessary to demonstrate them. The posterior pair has been seen

pulsating, one on each side of the urostyle, a little in front of the cloacal aperture.

Communicating with the lymphatic vessels are a number of large spaces such as the *subcutaneoums lymph spaces* and the *subvertebral lymph sinus* which have already been seen.

THE DIGESTIVE SYSTEM.

The digestive system comprises of the alimentary canal and the glands connected with it, namely the liver and pancreas. The alimentary canal consists of the buccal cavity, gullet, stomach, small and large intestines and the cloaca. The *mouth aperture,* which is extremely large, leads into the buccal cavity. The food is not masticated but swallowed whole. There are no salivary glands other than the microscopic follicles which supply the sticky saliva which enables the frog to catch its prey. The *buccal cavity* has already been examined. The *æsophagus* or gullet comes next. The student has noted its commencement at the posterior end of the buccal cavity. It is about three-quarters of an inch in length and leads into the stomach.

The *stomach* is a thick-walled, elongated and somewhat fusiform organ lying in the left upper part of the body-cavity. Its anterior end into which the œsophagus opens is called the *cardiac end* from its proximity to the heart. The posterior end is called the *pylorus*. If the latter is felt between two fingers it will be found to be firm in consistence. This is due to the presence of a strong circular band of muscle fibres called the sphincter. During life this band remains contracted but relaxes at intervals so as to allow portions of the contents of the stomach to pass into the small

intestine. It acts as a gate-keeper, hence the name pylorus or pyloric sphincter. The membrane lining the inner surface of the stomach is rugose, *i.e.*, is thrown into ridges with intervening grooves. The ridges run in a longitudinal direction and serve to increase the internal surface. The stomach produces a secretion called the *gastric juice* which contains the ferment, pepsin, and a little hydrochloric acid which gives it an acid reaction. Pepsin breaks up the insoluble proteids of the food into soluble substances called peptones. The acid is essential to the action of the pepsin.

The *small intestine* comes after the stomach. It consists of a short straight portion called the *duodenum* which forms with the stomach a U-shaped loop, followed by a long convoluted tube, the *ileum*. There is no cæcum in the frog. The *large intestine* is a straight wide tube which cannot be divided into a colon and rectum. It is continued posteriorly into the *cloaca*.

The visible glands in connection with the alimentary canal are the liver and pancreas. The *liver* is a large dark coloured organ consisting of a right and a left lobe. The left lobe is again divided into two parts. Raise the right lobe so as to expose its under surface. It will then be seen to be likewise subdivided though to a lesser degree, and the round bluish-green *gall-bladder* will be seen on its under surface. The secretion of the liver is a greenish fluid called *bile*. It leaves the liver by several small channels, the *hepatic* ducts, which join together and effect a junction with the *cystic* duct coming from the gall-bladder. The single duct thus formed, the *common bile duct*, passes through the substance of the pancreas and opens into the duodenum near its middle. On its way it

is joined by several small ducts from the pancreas. Therefore the common duct pours into the duodenum the secretions of both liver and pancreas.

The student should spread out the mesentery extending between the stomach and the duodenum. The *pancreas*

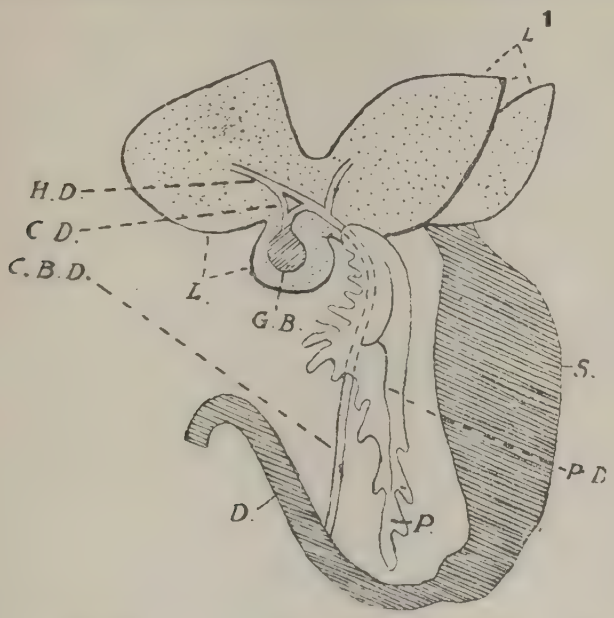

Fig. 129.—*Diagram of the liver pancreas stomach and doudenum of the Frog.*

C. B. D.—Common bile duct.
C. D.—Cystic duct.
D.—Duodenum.
G. B.—Gall-bladder.
H. D.—Hepatic duct.
L.—Right lobe of the liver.
L1.—Left lobe of the liver.
P.—Pancreas.
P. D.—Pancreatic duct.
S.—Stomach.

will then be seen as a cream-coloured, compact, Y-shaped body. If the gall-bladder is now gently squeezed, the middle part of the duodenum will be seen to become with greenish bile and the course of the common duct can be made out.

The bile is alkaline and helps in the digestion of fat and absorption of fatty acids. The pancreatic secretion is also alkaline. It contains three ferments, namely, trypsin, amylop-

sin and steapsin. Trypsin converts the proteids and peptones passed on by the stomach into soluble amino-acids, amylopsin converts the insoluble starch into soluble sugars; steapsin breaks up fats into fatty acids and glycerin. The latter goes into solution while the fatty acids are held in solution by the bile-salts while a small amount combines with the alkalies forming soluble soaps. This conversion of insoluble food material into a form in which it can be absorbed from the alimentary canal is called *digestion*.

The amino-acids and sugars are then absorbed into the blood vessels. The fatty acids and glycerin, as they pass through the epithelial cells lining the small intestine, are recombined to form globules of neutral fat. The greater part of this fat passes into the lymphatics, the remainder is taken up by leucocytes which enter the blood stream and carry it to different parts of the body. The products of digestion are thus conveyed to the different parts of the body and are utilised for the nutrition and repair of tissue cells. The insoluble products are passed on to the large intestine where some of the water is absorbed leaving the semi-solid fæces to be ejected through the cloaca.

THE RESPIRATORY SYSTEM.

The student has already seen the mechanism by which air is inhaled and exhaled. In inspiration the anterior nares are at first opened, the floor of the mouth is depressed, and air thus sucked into the buccal cavity. The anterior nares are then closed, the floor of the mouth is raised and the air in the buccal cavity forced through the glottis into the lungs. In the rabbit and man the mechanism of inspiration is different and consists in enlarging the cavity of the chest so

as to create negative pressure within it. The lungs therefore expand and air is sucked into them. In other words, the air is *pumped* into the lungs of the frog; it is *sucked* into the lungs of Man.

In expiration the elastic lungs contract and at the same time the anterior nares are opened so that the impure air passes to the exterior.

The air entering the mouth through the nares and nasal passages passes through the glottis into a small chamber which contains the vocal cords and therefore corresponds to the larynx in man. On each side the chamber opens into the corresponding lung. There is neither trachea nor bronchus in the frog. The lungs are thin-walled hollow sacs unlike those of the rabbit which appear solid and are of a spongy texture. The inner surface presents a pitted appearance due to the network of small vessels which project from the surface. An exchange of gases takes place through the thin walls of these vessels, oxygen passing in and combining with the hæmoglobin in the red blood cells and carbon dioxide passing out to the air in the lungs.

It must be remembered that the skin is an important respiratory organ in the frog and a large amount of impure blood is sent to it by the cutaneous branch of the pulmo cutaneous artery.

THE URINO-GENITAL ORGANS.

The urinary system consists of the kidneys, their ducts or ureters and the bladder. The *kidneys* are two dark red, elongated, flattened bodies lying close together one on each side of the middle line dorsal to the pleuro-peritoneum. On the ventral aspect of each there is an elongated yellow organ the *adrenal body*. The kidneys are richly supplied with

blood from two sets of vessels, namely, the renal portal veins and the renal arteries. The kidney contains a large number of much coiled delicate tubules which open into the ureter and round which the blood vessels ramify. The tubules take up water with certain dissolved substances like urea, guanin, uric acid and salts from the blood. This solution constitutes the urine. The urine flowing along the tubules reaches the *ureter* which is a whitish thin-walled tube lying along the outer border of each kidney. Each ureter passes backward and opens separately on the dorsal wall of the cloaca. The *bladder* is a thin-walled, bilobed sac lying at the posterior end of the body-cavity. It has no direct connection with the ureters. It opens by an aperture in the ventral wall of the cloaca. This aperture is opposite the two openings of the ureters in the dorsal wall. Hence the urine coming down the ureters may either directly pass to the exterior through the cloaca or may pass into the bladder and be temporarily stored.

In the male frog the gonads or essential organs of reproduction are the two *testes*. They are yellow cylindrical bodies with rounded ends. In the breeding season they increase in size and assume a deeper yellow colour. They lie on the ventral surface of the kidneys, suspended by a short fold of peritoneum. The testes produce the male gametes or spermatozoa. These can easily be seen. Put a drop of normal saline solution on a slide and squeeze the cut surface of a testis into the drop. Place a cover-glass over the drop and examine with the one-sixth inch objective. The actively motile spermatozoa will then be seen in large numbers with elongated rod-like heads and long thin lashing tails.

The spermatozoa leave the testes by several slender ducts. These are the *vasa efferentia* which can be seen in

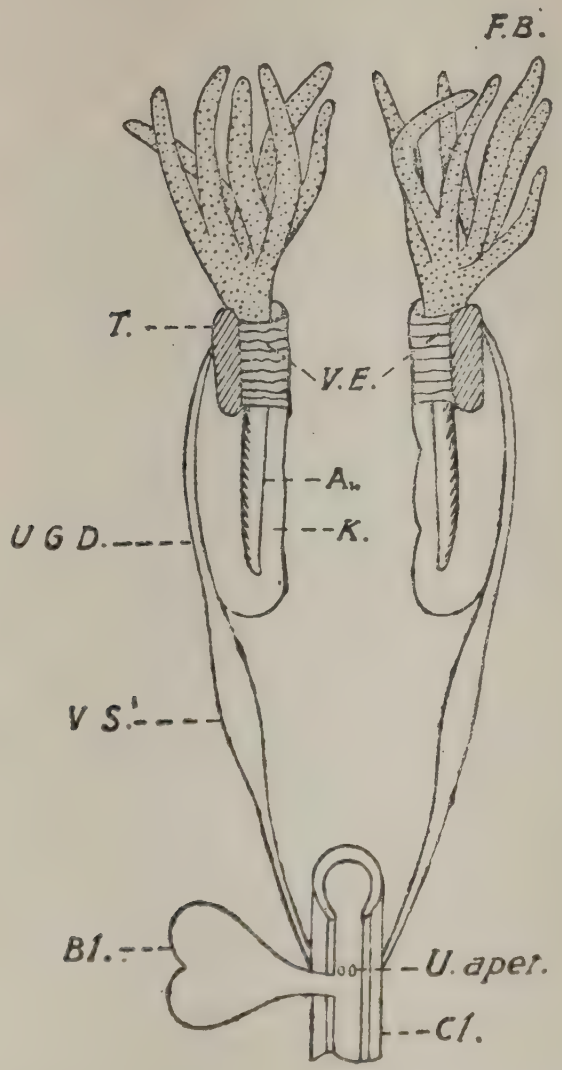

Fig. 130.—*Diagram of the urino-genital organs of the male Frog.*

A.—Adrenal body.
Bl.—Urinary bladder.
Cl.—Cloaca. F.-B.—Fat-body.
K.—Kidney.
T.—Testis.
U. aper.—Apertures of the ureters.
U. G. D.—Wolffian or genito urinary duct.
V. E.—Vasa efferentia.
V. S.—Vesicula seminalis.

the suspending fold of peritoneum by lifting up the testis. They run from the testis to the inner margin of the corresponding kidney and communicate with the kidney tubules along which the spermatozoa pass into the ureter. The latter therefore acts both as *vas deferens* and as duct of the kidney and in the male frog should be called the *genito-urinary duct.* In the male *R. tigrina* the portion of the duct lying behind the kidney is slightly dilated in a spindle shape. This part corresponds to the *vesicula seminalis* which, in the edible frog, forms a reletively large sac projecting from the outer side of each ureter. In the female *R tigrina* the ureters are slender and of uniform width.

If in the male frog the pleuro-peritoneum lying to the outer side of each kidney be carefully examined, a very slender dark line will be seen running longitudinally in the substance of the membrane. Trace it forward and it will be seen to end close to the root of the corresponding lung. When traced backward it disappears from view a little behind the posterior end of the kidney. Occasionally it forms a more prominent white streak. This is the remnant of *Muller's duct* seen in the embryo ; in the female it develops into the oviduct.

In the female frog the essential organs of reproduction are the two *ovaries.* Each lies ventral to the kidney of its side and is suspended, like the testis, by a short fold of peritoneum. The ovaries are soft masses of a dark colour. They become very large during the breeding season. Their surface is covered by numerous ova in various stages of growth. Immature ova look like mere white specks while mature eggs are as large as small shot. They are black near the attached end and white on the free surface. When fully deve-

loped the ova become detached from the surface of the ovary and fall into the cœlomic cavity whence they pass to the exterior by means of the oviducts.

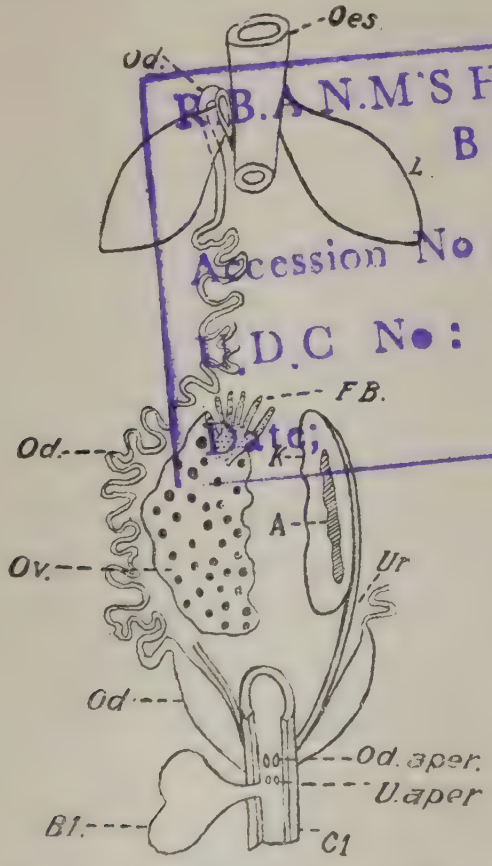

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Fig. 131.—*Diagram of the urino-genital organs of the female Frog.*

A.—Adrenal body.
Bl.—Urinary bladder.
Cl.—Cloaca.
F. B.—Fat body.
K.—Kidney.
L.—Lung.
Od.—Oviduct.
Od. aper.—Apertures of the oviducts.
Oes.—Œsophagus.
Ov.—Ovary.
U. aper.—Apertures of the ureters.
Ur.—Ureter.

The *oviducts* are two long tubes commencing in the anterior part of the cœlomic cavity near the roots of the lungs and running backward to terminate by two separate openings, in the dorsal wall of the cloaca a little anterior

to the openings of the ureters. Each oviduct consists of three parts. The anterior part is a short, thin-walled tube without convolutions. When traced forward it will be seen to pass behind the lung and then to arch over the root of the lung. It commences in the angle between the root of the lung and the œsophagus by a funnel-shaped mouth which opens into the cœlomic cavity. The middle part is long and convoluted. Its walls are thick and contain glands which secrete the albumen with which the eggs become coated. The posterior part is short, thin-walled and not convoluted, but it is very wide and distensile. The ova accumulate in this portion just before laying. This part ends in the cloaca.

In both sexes, but especially in males, bunches of yellow processes, *the fat bodies*, will be seen attached to the anterior and of each reproductive gland. These vary greatly in size as they constitute a reserve of fat material, large at the end of the Monsoon, small at the end of the dry weather after hibernation.

The student must have noticed the absence of external genital organs in either sex. With the onset of the breeding season the male goes forth with his croaking love-song in rearch of a mate, finds one and clasps her in a firm embrace with his fore limbs for days together till the ova are discharged from the cloaca. He then ejects the semen teeming with spermatozoa. *Fertilisation* or the union of an ovum with a spermatozoon takes place in the water. The albumen with which the ova have been coated in the oviduct, absorbs water and swells up into a thick jelly-like mass homologous with the white of the hen's egg, and glues the ova together.

This mass with the embedded ova is familiarly known as the frog's "spawn."

THE DUCTLESS GLANDS.

The student has already noticed the *thyroid glands* and *adrenal bodies*. The *spleen* will be seen attached to the mesentery close to the commencement of the large intestine. It is a small, spherical body of a dark red colour. The *thymus* glands are two small flattened cream-coloured bodies. The student should cut down boldly a little in front and to the inner side of the articulation of the jaws. If the knife is kept close to the bone the thymus will come into view at some depth from the surface, closely applied to the inner aspect of the posterior limb of the pterygoid bone.

The student has observed that the liver and pancreas possess ducts to convey their secretions. The ductless glands have no such channels and their products are added to the blood circulating through them. Consequently the blood vessels convey their secretions to the tissues.

THE NERVOUS SYSTEM.

This is the governing system of the body. It originates and co-ordinates movements, receives and interprets sensations and regulates all the functions of the body. It consists of a *central* and a *peripheral* part.

The central nervous system consists of the brain and spinal cord enclosed in the cranium and vertebral column, respectively. The peripheral nervous system consists of the cranial and spinal nerves passing from the brain and spinal cord to the periphery where they terminate either in the organs of special sense or in the nerve-endings in the skin,

muscles and tendons. There is in addition a sympathetic nervous system which regulates the viscera and blood-vessels.

The student will best grasp the morphology of the brain and spinal cord if he keeps in mind that they form a single

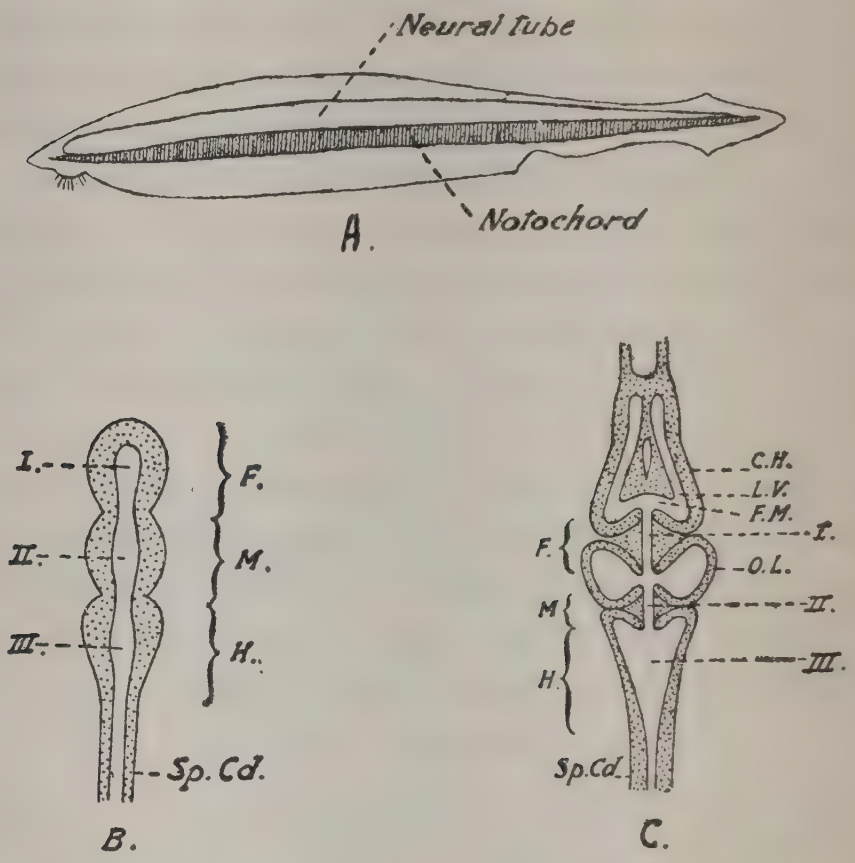

Fig. 132.—*Diagrams to show the uniform tube-like central nervous system in the Amphioxus (A), a tube with three anterior enlargements as seen in many Fishes (B), and the three enlargements with secondary outgrowths as seen in the Frog (C).*

C. H.—Cerebral hemispheres.
F.—Fore-brain.
F. M.—Interventricular Foramen.
H.—Hind-brain.
L. V.—Lateral ventricle.
M.—Mid-brain.
O. L.—Optic lobes.
Sp. Cd.—Spinal cord.

I.—Cavity of the anterior cerebral vesicle (3rd ventricle).
II.—Cavity of the middle cerebral vesicle (Iter).
III.—Cavity of the posterior cerebral vesicle (4th ventricle).

structure arising in the embryo as a longitudinal groove in the epiblast. Fig. 137. The sides of this groove grow upward and inward and meet dorsally to form a tube. This tube is continuous. Hence the brain and cord which are developed from it also form a single continuous tube.

In Amphioxus which is closely allied to the vertebrates, it remains throughout life as a tube of almost even bore ; but in the Fishes as well as in the Frog and all higher vertebrates the tube dilates at the oral end into at least three vesicles with their contained hollows or "ventricles." These are the *anterior*, *middle* and *posterior cerebral vesicles*. Secondary outgrowths like the hemispheres arise from these vesicles and in the higher animals like Monkeys and Man, become so largely developed that they overlap and conceal the three primary divisions. Moreover, the vast thickening of the walls of these divisions causes great relative diminution in the size of their cavities. But in all these animals, even the highest, the central nervous system passes in the embryo through the successive stages of (*a*) groove, (*b*) simple cylindrical tube, and (*c*) tube with the three vesicular enlargements at its anterior end. These enlargements constitute the brain while the rest of the tube is called the spinal cord.

Unfortunately the ancient anatomists began their study of morphology at the wrong end—wrong from a scientific point of view,—of the animal scale, by first studying adult human and other mammal brains and only later examining those of the lower animals. Hence the names given to the various regions are strange, weird and incorrect from a homological point of view. In the human brain by far the largest

structures are two antero-lateral outgrowths of the anterior vesicle, the *cerebral hemispheres*. What more natural for the early anatomist than to call their cavities—much the largest—THE ventricles ? And they did so. Later they found another median cavity ; this they called the Third Ventricle having already discovered the two big lateral ones. Then they easily found another in the hind-brain. They naturally called this the Fourth Ventricle. Then they found there was a narrow channel in the mid-brain joining the third with the fourth ventricle and, as a matter of course, they called it the Passage or in Latin, Iter, from the third to the fourth ventricle (*Iter a tertio ad quartum ventriculum*) though in reality it is part of the lumen of the original tube and constitutes the ventricle of the mid-brain. We have thus arrived at the anomalous nomenclature by which

the ventricle of the anterior vesicle or fore-brain is called the third
" " middle vesicle or mid-brain " " the iter
" " posterior vesicle or hind-brain " " the fourth.

The proper course would have been to call the third ventricle the " first," the iter the " second," and the fourth, the "third."

Dissection to Expose the Brain.

Make an incision in the skin in the mid-dorsal line extending from the nostrils to a point behind the posterior margin of the skull. Reflect the skin on each side. Flex the head slightly so as to put the membrane joining the skull with the atlas on the stretch. Cut through this with the point of a knife. Then introduce the point of the bone-pliers into the foramen magnum and cut the roof of the cranium longitudinally from behind forward, keeping well away from the median line. Repeat the same on the opposite side and lift off the

detached piece of bone. Continue this chipping process till the whole roof is removed. Examine the dorsal surface with the brain *in situ*. Having done this, gently remove the brain by cutting across the posterior end of the medulla and dividing the cranial nerves close to the bone. Next, expose the spinal cord by cutting the neural arches from before backwards on each side.

In the adult frog the brain is divisible into three parts, namely, the fore-, mid- and hind-brain, corresponding to the anterior, middle and posterior cerebral vesicles of the embryo, respectively.

The fore-brain is developed from the anterior cerebral vesicle. The walls of the vesicle persist as the *thalamencephalon,* while its cavity remains as the *third ventricle.* In the higher animals the size of the thalamencephalon is entirely dwarfed by certain outgrowths. Thus antero-laterally two hollow cerebral *hemispheres* arise ; a median outgrowth from its roof forms the *pineal body* ; in its floor is formed a funnel-shaped depression, the *infundibulum,* while its lateral walls become thickened to form the *optic thalami.*

The student will note that the cerebral hemispheres are not united together by their apposed surfaces. Their entire surface is smooth and devoid of grooves and convolutions. A small hollow outgrowth, the *olfactory lobe,* goes forward from the anterior end of each hemisphere. The adjacent surfaces of the two lobes are fused together. Gently pull apart the posterior ends of the hemispheres. This will bring into view the diamond-shaped roof of the third ventricle formed by a thin vascular membrane, the *anterior choroid*

plexus. The pineal body is a small rounded structure arising from the roof and provided with a stalk. The student will seldom see it, because as the bones of the cranium grow round

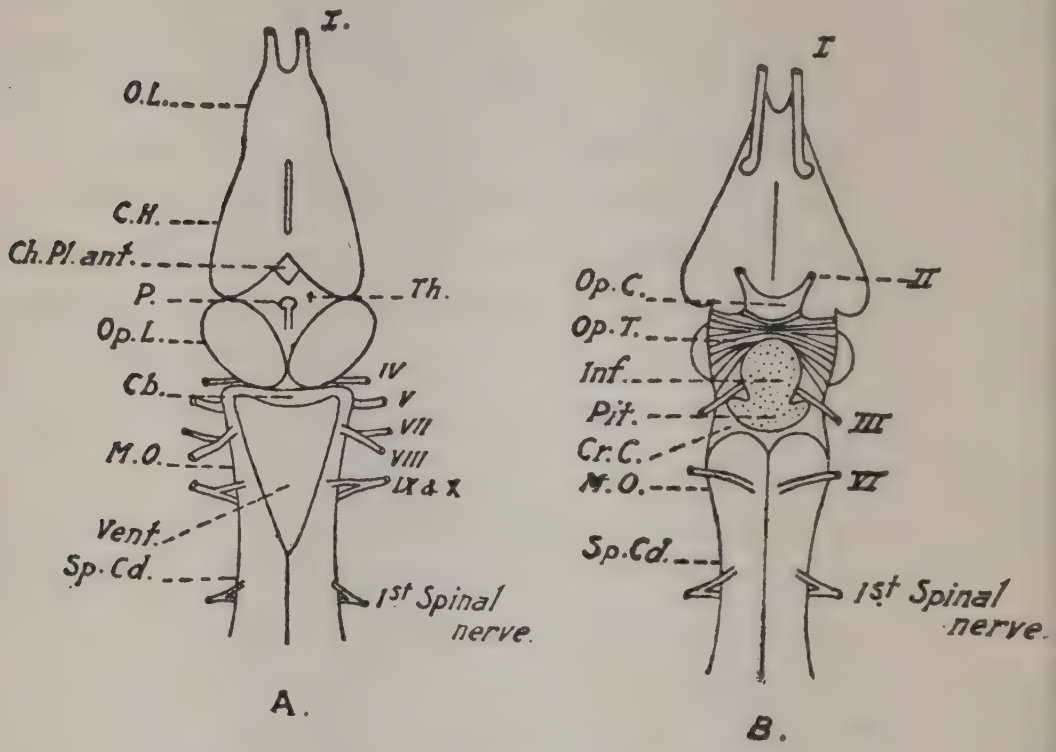

Fig. 133.—*Diagrams of the brain of the Frog—A. dorsal view, B. ventral view.*

I.-X.—Origins of the cranial nerves.
Cb.—Cerebellum.
C. H.—Cerebral hemispheres.
Ch. Pl. ant.—Anterior choroid plexus.
Cr. C.—Crus cerebri.
Inf.—Infundibulum.
M. O.—Medulla oblongata.
O. L.—Olfactory lobe.
Op. C.—Optic chiasma.
Op. L.—Optic lobe.
Op. T.—Optic tract.
P.—Pineal body and stalk.
Pit.—Pituitary body.
Sp. Cd.—Spinal cord.
Th.—Thalamencephalon.
Vent.—Fourth ventricle.

the brain they surround the stalk. Hence when the roof of the skull is removed the pineal body is torn from the stalk and remains outside the skull beneath the skin in the position of the brow-spot. When the brain is exposed the broken

bleeding end of the stalk alone is seen. The optic thalami cannot be seen from without. To demonstrate them, harden the brain in dilute formalin solution and make a horizontal section. The optic thalami will then be seen forming the lateral walls of the third ventricle. A small hemispherical structure, the *pituitary body*, is attached to the tip of the infundibulum.

The cavities of the cerebral hemispheres are the *lateral ventricles* which are continuous in front with the cavities of the olfactory lobes. Posteriorly each lateral ventricle communicates with the third through a small aperture, the *interventricular foramen.*

The mid-brain is developed from the middle cerebral vesicle. The floor of the vesicle becomes thickened and develops into two broad bundles of longitudinal nerve fibres, the *crura cerebri*, which join the hemispheres with the hind-brain. The roof grows out into two hollow ovoid prominences, the *optic lobes* or *corpora bigemina.* The cavity of the vesicle persists as a narrow channel, the *iter.*

The hind-brain is formed from the posterior cerebral vesicle. The floor and sides of the vesicle thicken to form the *medulla oblongata.* The roof for the greater part consists of a thin vascular membrane, the *posterior choroid plexus*, and contains no nervous tissue, being formed solely by the serous membrane which lines the ventricle coming into apposition with the *pia mater*, the membrane which covers the surface of the brain. In the frog the anterior part of the roof has a small transverse overhanging lip, the *cerebellum*, which in higher animals attains much greater development and may overlap the medulla oblongata completely. The cavity of the

posterior vesicle persists as the *fourth ventricle* which in the frog appears as a triangular space roofed only by the posterior choroid plexus. It is continuous in front with the iter and behind with the central canal of the cord.

The spinal cord is a hollow tube of nerve tissue enclosed by the vertebral column. In front it is continuous with the brain while posteriorly it narrows to a terminal thread-like portion, the *filum terminale*, lodged in the anterior part of the urostyle. It is grooved along both the ventral and dorsal surfaces, the grooves being called the *ventral* and *dorsal fissures*, respectively. Where the nerves that supply the fore- and the hind-limbs are given off the cord is enlarged, forming the *brachial* and *sciatic swellings*, respectively. The ventricle or lumen of the cord, called the *central canal* is extremely narrow. The cord is flattened dorso-ventrally and ten pairs of nerves will be seen to arise one behind the other from its sides. Each nerve arises by two roots, one *dorsal*, the other *ventral*, which soon unite together to form a single trunk, the *spinal nerve*. Each dorsal root presents a small enlargement or *ganglion*. The dorsal ganglia are enclosed in the *perigangliomic* or *chalk saccules* which are continued over the nerves throughout the intervertebral foramina. In the dissection of the body-cavity when the intestine is removed these sacs are seen from the ventral aspect as a row of chalky patches on each side of the vertebral column. On pricking these patches a milky fluid exudes which shows numerous lime crystals under the microscope. Irrigating with weak nitric acid dissolves these and assists dissection by rendering the roots clearly visible. The spinal nerves with the exception of the last pair leave the neural canal through the inter-

vertebral foramina. The last pair emerges through small apertures in the urostyle. The first passes through the intervertebral foramen between the first and second vertebræ, and the ninth through the foramen between the ninth vertebra and urostyle. As, however, the spinal cord is shorter than the vertebral column the posterior nerves have to run backward for some distance to reach their respective foramina. Hence the hind end of the neural canal is occupied by a bunch of slender nerve cords arranged round the filum terminale, thus forming the *cauda equina*, so named from its supposed resemblance to the tail of a horse.

The student can easily trace the posterior spinal nerves after their exit through the intervertebral foramina as they traverse the subvertebral lymph space dorsal to the pleuro-peritoneum.

The first spinal nerve is distributed chiefly to the muscles of the tongue. Hence it corresponds to the hypoglossal or the twelfth cranial nerve of the rabbit and man.

The second and third spinal nerves form the *brachial plexus*, which gives off the large brachial nerve going to the fore-limb, and also smaller branches to the anterior part of the body-wall.

The fourth, fifth and sixth nerves do not unite into a plexus but run separately and supply the parietes behind the fore-limbs.

The seventh, eighth and ninth spinal nerves unite to form the *lumbo-sacral plexus* which gives off the large sciatic nerve supplying the hind-limb, and also smaller twigs to the posterior region of the body-wall.

The tenth pair supplies the bladder, cloaca and the adjacent parts.

The student will now be able to understand the reason for the two enlargements of the spinal cord described above as the brachial and sciatic swellings. The former is at the level of origin of the second and third spinal nerves the chief distribution of which is to the fore-limbs while the latter lies at the site of origin of the nerves of the lumbo-sacral plexuses the main distribution of which is to the hind-limbs. The limbs contain a very large number of muscles compared with their size, and the adequate control of these necessitates a large accumulation of nerve cells.

Both the brain and spinal cord are surrounded by three membranes called the *meninges*. The innermost is the *pia mater* which is thin, transparent and for the most part adherent to the brain and cord. It dips into all the fissures and grooves on their surface. It is very vascular as it contains the vessels which supply the brain and cord. It is thickened in two regions over the dorsal surface of the brain where it forms the choroid plexuses. The student has already seen one covering the roof of the third ventricle, and the other lying dorsal to the medulla so as to form the greater part of the roof of the fourth ventricle. The pia mater shows numerous dots of black pigment. The outermost membrane is thick and fibrous and is closely applied to the inner surface of the cranium. It is called the *dura mater*. Between the dura mater and the pia mater is a third membrane, the *arachnoid*. The space between the arachnoid and pia mater contains a watery fluid called the *cerebro-spinal fluid*. A water-cushion is thus formed all round the brain and cord protecting them from shocks.

There are ten pairs of cranial nerves in the frog. These are present in all vertebrate animals and are arranged on the same general plan.

The first and second pairs are processes of the brain rather than "nerves." The *first* or *olfactory* nerve proceeds forwards from the anterior end of each olfactory lobe and is distributed to the nasal mucous membrane. It is the nerve of smell.

The *second* or *optic* nerve is concerned with vision. Each arises from the thalamencephalon as a band of nerve fibres, the *optic tracts*, which approach one another and meet at the base of the hemispheres to form the *optic chiasma* where a crossing of some of the fibres takes place. The fibres are then collected into two bands, the optic nerves, which emerge through large apertures in the sides of the cranium to be distributed to the retina or sensory coat of the eye.

The *third* or *oculo-motor* nerves arise between the crura cerebri on the ventral surface of the brain. As the name implies they are distributed to all the muscles which move the eye-ball except the superior oblique and external rectus. The third nerve leaves the cranium by a small aperture just behind the optic foramen.

The *fourth* or *pathetic* nerve arises just behind the optic lobes from the dorsal surface of the brain and leaves the skull through a minute aperture which lies in front of the foramen for the second nerve, and is just covered by the margin of the parasphenoid. It is distributed to the superior oblique muscle which rolls the eye-ball downward and outward.

The fifth to the tenth nerves arise from the medulla.

The sixth arises from its ventral surface while the rest spring from the lateral aspect.

The *fifth* or *trigeminal* nerve presents an enlargement shortly after its origin from the side of the medulla. This is named the *Gasserian ganglion* after the anatomist who first observed it. After leaving the skull the nerve divides into three main branches—hence the name trigeminal—the *ophthalmic*, *maxillary* and *mandibular* divisions. The first division supplies the skin in front of the eyes, the second supplies, as its name signifies, the skin covering the upper jaw, while the third is distributed to the skin and muscles of the lower jaw.

The *sixth* or *abducens* has its origin on the ventral surface of the medulla. It is closely united with the Gasserian ganglion of the fifth nerve. It supplies the external rectus muscle which rotates the eye-ball outward, that is abducts it. Hence the name of the nerve.

The *seventh* or *facial* nerve arises immediately behind the fifth and is closely united with the Gasserian ganglion of that nerve with which it keeps in contact till they emerge from the skull along with the sixth nerve by the aperture in front of the auditory capsule. It then divides into two branches, a sensory palatine, which supplies the mucous membrane of the roof of the mouth, and a motor branch to muscles connected with the hyoid and mandible.

The *eighth* or *auditory* arises with the seventh from the side of the medulla. It is distributed to the organ of hearing.

The ninth and tenth nerves arise together from the side of the medulla. The *ninth* or *glossopharyngeal*, owes its name to the fact that it is mainly distributed to the mucous mem-

brane of the tongue and pharynx. The ninth and tenth nerves leave the skull by an aperture external to the occipital condyle.

The *tenth* is called the *vagus* (Lat. wandering,) nerve from its extensive distribution, for it supplies the larynx, heart, lungs, stomach and intestines. From the fact that it supplies the lungs and stomach it is often called the *pneumogastric*.

The sympathetic nervous system consists of two chains of ganglia, one on each side of the middle line in the subvertebral lymph space. Each chain contains about ten ganglia linked together by slender nerves. Each ganglion communicates with the adjacent spinal nerve by a delicate filament, while branches are given off from the ganglia which are distributed to the blood-vessels and viscera. Anteriorly each chain joins the vagus nerve and terminates further forward by union with the Gasserian ganglion.

Special Senses.

The frog like ourselves, has five special senses, namely, those of smell, sight, hearing, taste and touch.

The student has seen that the organ of smell consists of two small chambers which open externally by the anterior nares, and into the buccal cavity by the posterior nares. Each chamber or *olfactory sac*, as it is termed, is lined by a peculiar mucous membrane. Some of the cells forming this membrane are specialised to receive olfactory stimuli. The free ends of these *olfactory cells* project from the surface of the membrane and bear delicate hair-like processes, while their proximal ends are continuous with the fibres of the olfactory nerves.

The eyes are the organs of sight. Each eye is provided

with accessory parts like the lids, conjunctiva, muscles and the secretory gland. The student has already observed the *lids*. They protect the eye from injury. The *muscles* enable the eye-ball to be rotated in any direction, and also effect its retraction. The *secretory gland* lies in the anterior part of the orbit. It secretes a fluid which lubricates the *conjunctiva*. The latter is a thin transparent membrane covering the exposed surface of the eye-ball and the inner surface of the lids.

The eye-ball possesses three coats called from without inward, sclera, choroid and retina. It contains in its interior the aqueous humour, the vitreous humour and the lens.

The *sclera* is the tough white outer coat. It is formed of fibrous tissue and is protective in function. Its anterior part is transparent and forms the *cornea*. Homologically it is the embryonic " optic capsule " which, unlike the auditory and olfactory capsules, does not fuse with the cranium. It consists solely of fibrous tissue in the Frog, Rabbit and Man though in certain Fishes and Reptiles it contains cartilage or even bone.

The *choroid* is the vascular coat of the eye. It lies be-between the sclera and retina. Its anterior part forms the *iris*, a muscular diaphragm with a central aperture, the *pupil*. The choroid supplies nourishment to the subjacent retina, for the latter has no blood-vessels. The iris is pigmented and has a beautiful golden metallic lustre. It acts as a diaphragm because by its contraction and relaxation the size of the pupil can be altered to regulate the amount of light entering the eye. Note that the pupil is not circular but elliptical and horizontal.

The *retina* is the innermost coat of the eye-ball. It is black because it contains a layer of pigment cells. It is the sensitive coat of the eye and has a complicated structure. It contains in its outer part a layer of specialised cells called *rod* and *cone cells* because their outer ends are either rod-shaped or cone-shaped. Light-waves falling on these cells give rise to impulses which are transmitted to the brain by the fibres of the optic nerves.

The *lens* is a transparent body lying just behind the pupil. It is a double convex lens and serves to focus external objects upon the retina.

The space between the lens and the cornea is called the *aqueous chamber*. The iris forms an incomplete curtain which divides it into anterior and posterior portions which are continuous, and contain a clear watery fluid, the *aqueous humour*.

Behind the lens there is a large space, the *vitreous chamber*, filled with a transparent, jelly-like substance, the *vitreous humour*.

The organ of hearing in vertebrates, in its most fully developed form, consists of three parts, namely, the external, middle and internal ears. The first two are only accessory parts, and convey the sound waves to the internal ear. The latter contains the essential organ of hearing and is present in all classes of vertebrates.

The external ear is absent in the frog, but is well developed in the rabbit. It consists of the auricle which collects the sound waves, and the external meatus, a short canal leading to the tympanic membrane. Both these being absent in the frog the tympanic membrane is on a level with the surface of the body.

The middle ear is called the *tympanum* or drum, for it consists essentially of a chamber having on its outer side a membrane stretched like that of a drum. It communicates with the exterior through the Eustachian recesses which the student has observed opening into the buccal cavity. This arrangement equalises the pressure on the two sides of the *tympanic membrane* and enables it to vibrate with ease when sound waves impinge upon it. A slender rod, the *columella*, made partly of bone and partly of cartilage, is attached by one end to the deep surface of the tympanic membrane, and by the other to the membrane stretched across the *fenestra ovalis*, a small oval aperture, in the wall of the auditory capsule.

The internal ear is called the *labyrinth* owing to its very complex shape. It consists of the auditory capsule of the skull and a membranous structure of similar shape, the *membranous labyrinth*, which is enclosed within the capsule.

The membranous labyrinth is not only the essential organ of hearing, but like the statocyst in Panulirus, is also the organ for detecting changes in the position of the body. In it we find two sacs, the *utricle* and the *saccule*, linked together by a narrow constricted portion. The utricle is connected with three *semicircular canals* which lie at right angles to one another. One end of each canal is dilated. The dilated part is called the *ampulla*. The saccule gives off a small blind pouch, known as the *cochlea*, poorly developed in the frog, and a narrow tubular process, the *endolymphatic duct*, which ends blindly.

The utricle and saccule are lined by an epithelium which presents patches of specialised cells bearing hair-like pro-

cesses at their free ends. *R. C.* the cells specially adapted to receive sonorous vibrations are situated in the cochlea. The ampullæ contain cells adapted for detecting changes in the position of the body.

The space between the auditory capsule and the membranous labyrinth is filled by a fluid called *perilymph.* The membranous labyrinth contains a fluid called *endolymph.* The vibrations of the tympanic membrane are transmitted by the columella to the membrane stretched across the fenestra ovalis. This conveys the vibrations to the perilymph, which in turn transmits them to the endolymph. The vibrations thus reach the specialised auditory cells, giving rise to impulses which are conveyed to the brain by the fibres of the eighth nerve.

The semicircular canals are organs for detecting changes in the position of the body. This is rendered possible by their arrangement in three planes at right angles to one another. Movements of the body in different directions cause movements in the endolymph in different canals, and thereby stimulate the hair cells in the corresponding ampulla. These cells give rise to impulses which are transmitted to the brain by the fibres of the eighth nerve and keep the brain constantly informed of any change of posture.

The mucous membrane lining the mouth and the dorsal surface of the tongue contains groups of specialised cells appropriate stimulation of which gives rise to sensations of taste. The resulting impulses reach the brain by the fibres of the glosso-pharyngeal nerve. On the dorsal surface of the tongue these cells are contained in small projections or *papillæ.*

The sense of touch is located in the skin which contains special nerve-endings. These give rise to impulses conveyed to the brain by the fibres of the sensory nerves supplying the skin.

The nerve-endings in muscles and tendons give rise to impulses which furnish information concerning the movement of the muscles. Consequently, they are of importance in the regulation and co-ordination of muscular movements.

R. B. A. N. M'S EDUCATIONAL CHARITIES
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PRINCIPLES OF EMBRYOLOGY.

The student has already observed the sexual reproductive cells or *gametes*. The female gamete or *ovum* of the Frog when mature is fairly large, being 1·5 mm. to 2 mm. in diameter, without taking into account the albuminous envelope. It is a spheroidal cell surrounded by a delicate *vitelline membrane*. The *cytoplasm* contains numerous granules of nutrient *yolk*. Embedded in the cytoplasm is the *nucleus* which contains several *nucleoli*. There is no centrosome in the mature ovum. The male gamete or *spermatozoon* is a smaller, motile cell, consisting of a short rod-like *head* which is the nucleus, a long lashing flagellum or *tail* which is the cytoplasm, and a *middle region* containing the centrosome at the junction of the head with the tail.

These highly specialised cells, so different from each other, are derived from cells which are apparently alike, the *primitive germ-cells* of the testes and ovaries. In both sexes these cells undergo a series of changes which are essentially identical. The changes may be divided into three stages in each case—a period of repeated division, a period of rest, and a period of maturation.

In the development of spermatozoa the primitive germ-cells undergo repeated division. In these divisions the nucleus divides by the indirect method, that is by karyokinesis or mitosis. The resulting cells are known as the *sperm-mother-cells*.

The nucleus of the body-cells of all animals and plants shows during cell-division a number of thread-like structures called *chromosomes*. This number is constant for organisms of the same species. It is an even number except in a few animals. The body-cells of the frog possess nuclei with twenty-four chromosomes. This number persists in the primitive germ-cells of the testes and the sperm-mother-cells formed from them.

The division of the sperm-mother-cells ceases after a time. The period of rest now begins. During this the nucleus undergoes complicated changes and the cell so altered is known as the *primary sperm-cell.*

The cell now enters upon the period of maturation. The primary sperm-cell divides and the resulting cells are called *secondary sperm-cells*. This is called the *first maturation division*. The nuclear changes during the period of rest are such that, when the primary sperm-cell divides into the secondary sperm-cells, the nuclei of the latter contain only half the number of chromosomes found in the body-cells. Thus the secondary sperm-cells of the frog contain only twelve chromosomes. The first maturation division therefore is a reducing division, and differs from an ordinary karyokinesis in which the nuclei of the parent and daughter-cells contain an equal number of chromosomes.

The secondary sperm-cells now undergo division. This is called the *second maturation division.* It is of the ordinary karyokinetic type for the daughter-cells contain nuclei with twelve chromosomes each, that is the number present in the parent cell. The cells resulting from the second maturation division undergo a remarkable change of form into the elon-

gated motile spermatozoa. Therefore each primary sperm-cell gives rise after the two maturation divisions to four mature spermatozoa, each provided with only half the number of chromosomes seen in the body-cells.

Similarly, in the female the primitive germ-cells of the ovaries divide a large number of times. The cells so produced are called the *egg-mother-cells*. Like the sperm-mother-cells their nuclei contain the full number of chromosomes.

During the subsequent period of rest the nucleus undergoes complex changes, while the cytoplasm becomes loaded with yolk granules. The cell so altered is the *primary egg-cell*.

The period of maturation now supervenes. The primary egg-cell divides, but instead of producing two cells of equal size like the secondary sperm-cells the resulting cells are very unequal. The division results in a large cell which is the *secondary egg-cell*, and a small one called the *first polar body*. This, the first maturation division, is a reducing division, and the daughter-cells have only half the number of chromosomes found in the body-cells.

The second maturation division is also unequal, the secondary egg-cell producing a large cell which is the mature ovum and a small one named the *second polar body*. Usually the first polar body divides at the same time. The second maturation division is of the ordinary karyokinetic type so that the mature ovum contains half the number of chromosomes found in the body-cells.

The process is therefore the same in the two sexes. The only difference is that whereas in the male, the four cells resulting from each primary sperm-cell are equal, in the

female, the primary egg-cell gives rise to three small pola cells and a single large cell, the mature ovum.

In the frog and most other Amphibia, the second pola body is not extruded until after fertilisation, which occu just after the egg is laid. In most other animals the extru sion of the second polar body occurs while the egg is travers ing the oviduct.

Fertilisation consists in the fusion of the male and fema gametes. It takes place in the water. Only one spe matozoon bores its way through the vitelline membran Its head, now termed the *male pronucleus*, fuses with th *female pronucleus* or nucleus of the mature ovum. The ta gets detached from the head, degenerates and disappears. Th fertilised ovum is called the *oosperm* or *zygote*. The latte contains twenty-four chromosomes, the male and fema pronuclei each contributing twelve. The number charac teristic of the body-cells is thus restored. This contributio of half the chromatin material by each gamete, and the fac that the offspring inherits characters of both parents sug gest that the chromosomes have important functions as ca riers of hereditary characters.

The zygote as seen in the "spawn" consists of an uppe dark portion, and a lower white one in which the yolk granule are more abundant.

DEVELOPMENT.

After fertilisation the ovum undergoes developmen This term implies all the changes which result in the for mation of an adult individual from the zygote.

The early stage of development consists in the *segmentatio*

of the oosperm, that is, the latter undergoes repeated division. The first cleavage is vertical and divides the entire egg into two cells. Each of these again divides vertically but in a plane at right angles to the first. So far the resulting cells are all alike. These four cells now divide horizontally, giving rise to eight cells. This cleavage is important because the upper four cells differ from the lower four. The upper four are small, black and their cytoplasm contains but few yolk granules ; the lower four are large, white and their cytoplasm is laden with yolk granules.

Fig. 134.—*Diagrams showing the first three cleavages in the segmentation of the ovum of the Frog.*

As each cleavage completely divides the cells into two, the segmentation is said to be *complete* or *holoblastic*. But owing to the accumulation of yolk granules at the lower pole of the zygote, the cleavage does not result in cells of equal size. Hence the segmentation is holoblastic and *unequal*.

The segmentation proceeds by further vertical and horizontal divisions, but soon the upper cells take on more rapid multiplication than the lower.

At the close of segmentation the egg consists of a hollow ball of cells called the *blastosphere* or *blastula*. The cavity in its interior, the *blastocœle* or *segmentation cavity*, is filled with fluid.

The small black cells at the upper pole, owing to their more rapid division, gradually encroach on the lower white

pole until a small circular aperture is left through which the yolk-laden cells remain visible on the surface. This aperture is called the *blastopore*; the plug of yolk-laden cells with which it is filled is known as the *yolk-plug*.

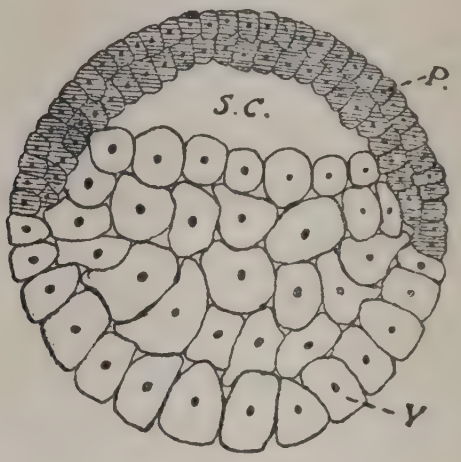

Fig. 135—*Vertical section of the ovum of the Frog at the close of segmentation.*

P.—Pigmented cells. S. C.—Segmentation cavity.
Y.—Yolk-laden cells.

The small black cells constitute the *epiblast*. The other two germinal layers, namely, the hypoblast and mesoblast, are differentiated somewhat later.

The blastopore marks the posterior end of the embryo. A tiny cleft appears among the yolk-laden cells, close to the upper margin of the blastopore. At the same time a limited ingrowth of the epiblast takes place from the upper margin of the blastopore along the roof of the cleft. The cleft gradually deepens, and as it proceeds towards the anterior end of the embryo it widens out forming a cavity called the *primitive gut* or *archenteron*. With the growth of the archenteron the segmentation cavity is pressed aside and finally obliterated

The embryo at this stage therefore consists of a cavity, the archenteron, surrounded by several layers of yolk-laden cells which, in turn, are surrounded by the epiblast cells except at the blastopore.

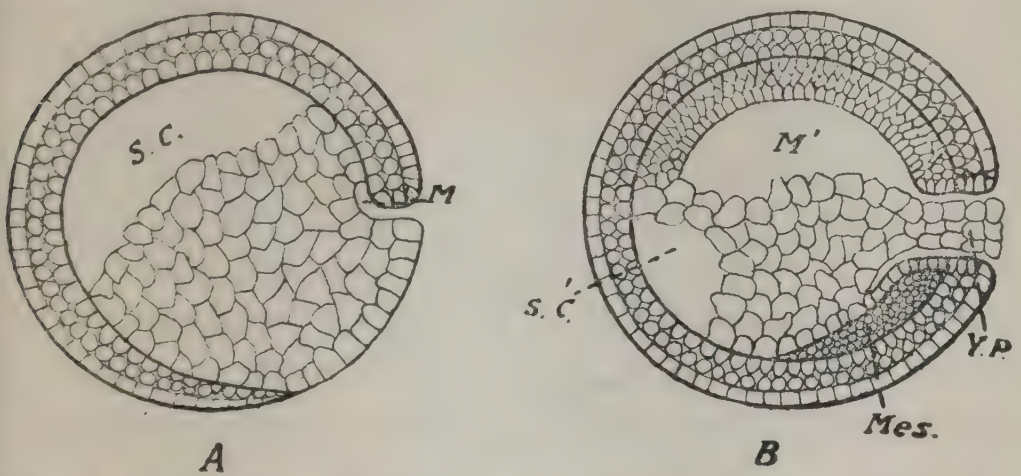

Fig. 136.—*Diagrams illustrating the formation of the primitive gut (archenteron) and obliteration of the segmentation cavity. Note the encroachment of the pigmented cells over the surface of the ovum.*

M.—Commencing archenteron.
M1.—Archenteron at later stage.
Mes.—Mesoblast.
S. C.—Segmentation cavity shown muchreduced at s. c.
Y. P.—Yolk-plug filling the blastopore.

The layer of cells lining the archenteron is the *hypoblast*. A third layer of cells appears between the hypoblast and the epiblast. It is called the *mesoblast*.

From these three germinal layers the various parts of the embryo are developed. The epiblast gives rise to the nervous system, the epithelium of the skin and cutaneous glands, the lens, the lining membranes of sensory organs and the epithelium lining the mouth and cloaca. From the hypoblast arise the notochord and the epithelium of the alimentary canal with its outgrowths—the lungs, the secreting cells of

the liver and pancreas with their ducts and the urinar bladder. All the remaining structures, the connective tissue muscles, skeleton, the circulatory and urino-genital system and the pleuro-peritoneum are derived from the mesoblast

Three very important structures now appear in the em bryo, namely, the notochord, the neural tube and the cœlom or body-cavity.

The hypoblast along the mid-dorsal line of the archen teron undergoes thickening. This thickening is gradually pinched off from the archenteron and its cells become differ entiated to form a solid rod of cells, the *notochord*, the pri mitive axial skeleton of the embryo. Certain animals closely allied to vertebrates, possess no vertebral column, but have

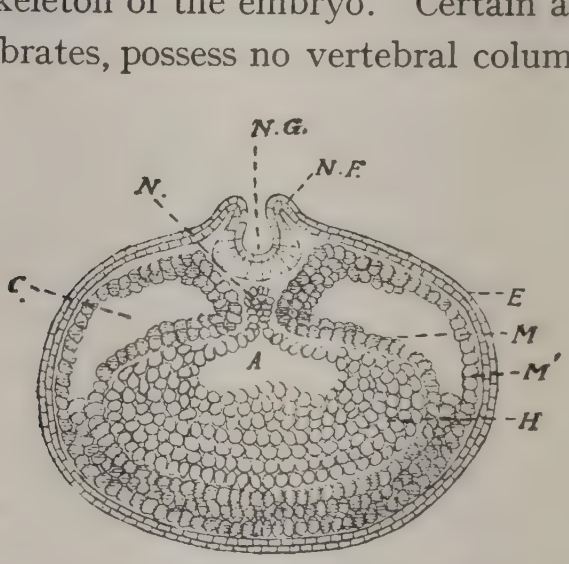

Fig. 137.—*Transverse section through the embryo of the Frog showing the three germinal layers and the formation of the neural tube and notochord.*

A.—Archenteron.
C.—Cœlom.
E.—Epiblast.
H.—Hypoblast.
M.—Mesoblast (visceral layer).
M1.—Mesoblast (parietal layer.
N.—Notochord.
N. F.—Neural fold.
N. G.—Neural groove.

notochord which shows their relationship to the vertebrates. Hence these animals are included with the vertebrates in a common group, the Chordata.

At the same time the cells of the epiblast in the mid-dorsal line proliferate and form an elongated plate of cells, the *neural plate*. On each side of this plate the epiblast is raised into ridges called the *neural folds*, thus giving rise to a groove termed the *neural groove*. The neural folds as they grow, arch over and fuse with each other, converting the groove into a tube, the *neural tube*, which is soon constricted off from the surface epiblast. The lumen of the neural tube com-

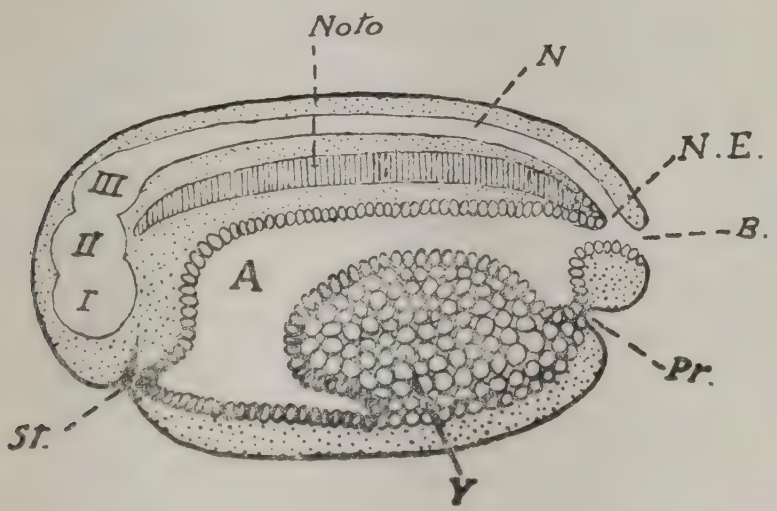

Fig. 138.—*Sagittal section through the embryo of the Frog showing the neural tube with three anterior enlargements. The stippled area is the mesoblast.*

A.—Archenteron.
B.—Blastopore.
N.—Neural tube.
N. E.—Neurenteric canal.
No to.—Notochord.
Pr.—Proctodæal dimple.
St.—Stomodæal dimple.
Y.—Yolk-laden cells.
I. II. III.—Anterior, middle and posterior cerebral vesicles.

municates for a time with the archenteron by the *neurenteric canal* ; this channel is soon obliterated.

The mesoblast splits into two layers, an outer or *somatic* layer in contact with the epiblast, an inner or *visceral* layer in contact with the hypoblast. The space between the two layers is the *cælom* or body-cavity.

The embryo now becomes elongated, and its body is divided into distinct regions. Its broad anterior half is marked off from the narrow posterior region, the tail, which shows active lashing movements even before the embryo is hatched.

A dimple called the *proctodæum* appears on the ventral surface near the root of the tail. Here the epiblast is invaginated. The dimple gradually deepens and ultimately opens into the archenteron before the embryo is hatched. A definite cloacal aperture is thus formed. Another dimple called the *stomodæum* appears on the ventral aspect of the head causing a similar invagination of the epiblast. It is the commencement of the oral aperture. It does not communicate with the archenteron at the time of hatching. The student should note that the mouth and cloaca both arise as invaginations of the epiblast and are consequently lined by it. A small sucker is developed immediately behind the stomodæum. Two branched processes project from each side of the head. These are the external gills.

The embryo now escapes from the surrounding jelly and becomes a small fish-like, free-swimming animal, called the tadpole.

For the first few days it is unable to feed as the stomodæum does not open into the archenteron. Respiration is carried on by means of the external gills. The animal either

swims about, or attaches itself to water weeds by means of the sucker.

Soon, however, the stomodæum communicates with the archenteron. Horny plates develop along the jaws, and horny prominences appear on the lips. By means of these it nibbles at the weeds, being a strict vegetarian at this period of its existence. The archenteron rapidly elongates and the intestine is seen coiled like a watch-spring through the translucent abdominal wall. The animal rapidly grows in size. A third pair of external gills grows out. The tadpole now begins to see owing to the development of the eyes.

As the power of locomotion is perfected the sucker is no longer required and atrophies. On each side of the head four slit-like openings, the *gill-clefts*, appear one behind the other posterior to the external gills. These clefts lead into the pharynx. Internal gills, delicate thin-walled tufts richly supplied with blood, are developed in connection with each gill-cleft. A hood-like fold of skin, the *operculum*, arises on each side of the head in front of the gills and grows backward over them so as to form a *gill-chamber*. The two opercula meet each other ventrally, and their posterior margins fuse with the body-wall, leaving only a small aperture on the left side which communicates with both gill-chambers. The external gills atrophy shortly after the appearance of the internal and the tadpole respires essentially like a fish. Water taken in by the mouth passes through the gill-clefts into the gill-chambers bathing the gills on its way. It then flows to the exterior through the aperture on the left side.

The limbs now develop. For a time only the hind-limbs are visible as the fore-limbs are under cover of the opercula.

Shortly after the tadpole is hatched there appear on the sides of the alimentary canal just behind the pharynx, two pouches which, gradually enlarging, become the lungs. The animal now frequently comes to the surface to take in a mouthful of air and as it dives back, leaves behind a tiny bubble of gas. This shows that breathing by the lungs is taking place. For a time respiration occurs both by the lungs and the internal gills. The latter, however, soon atrophy. The tail begins to shrink.

The animal undergoes a remarkable series of changes, as a result of which it is transformed or *metamorphosed* from the fish-like tadpole into the air breathing, terrestrial frog. The mouth becomes wide and loses the horny plates and prominences, teeth appear, the tongue becomes large, the fore-limbs emerge from under cover of the opercula, the gills become functionless, the gill-clefts are closed up and the animal has the form of an adult frog except for the presence of a tail. It respires exclusively by the lungs and skin, and lives on a purely animal diet.

The tadpole is the larval stage of the frog. The series of changes which it undergoes from the time it is hatched to the putting on of the adult form is called metamorphosis, the larva being entirely independent of its parents during the process of change.

Throughout the vegetable and animal kingdoms we find a more or less regular gradation from the lowest to the highest types. This and other observations led to the belief that

the higher forms are descended in the course of ages by a series of stages from common ancestors resembling, lower organisms.

Embryology furnishes evidence which lends support to this view. The larval stage of many animals has characteristics which resemble those of animals of a lower type. For example the tadpole resembles a fish in possessing a tail and gill-clefts. Moreover, there is a similarity between the tadpole and the young stage of the Mud Fish, the highest of the Fishes, which resembles the Amphibia in possessing both lungs and gills.

Observations like these suggest two theories—first, that frogs are descended from fish-like ancestors, or that both frogs and fish come from a common ancestor ; and, secondly, that every frog in the course of development from the egg to the adult condition, passes through stages which indicate its ancestral relationship to a fish ; and that frog and fish alike ultimately trace their descent to a protozoan ancestor, resembling the one-celled ovum. The first conclusion is in accord with the theory of evolution. The second is the recapitulation theory according to which the development of the individual is an epitome or recapitulation of its ancestral history.

PRINCIPLES OF BIOLOGY.

PRINCIPLES OF CLASSIFICATION.

All substances are popularly classified as belonging to the Animal, Vegetable or Mineral Kingdoms. In the preceding pages we have learnt the characteristics of living organisms and we have no difficulty in distinguishing the living organism from the lifeless mineral. Nor is it difficult to say whether one of the higher or more complicated beings is an animal or a plant, but, as we descend the scale, we find there is no rigid boundary line between the animal and the vegetable kingdoms and it is difficult to define the most lowly organisms as either plants or animals.

Haeckel, therefore, proposed that the organisms on the boundary line should be classified in a third kingdom or rather a neutral state to which he gave the name Protista. (Gr. *Protos*, primitive, first : *ista*, beings.) This new classification is however neither logical nor necessary, for there is quite as much difficulty in defining the boundary between the Protist and the Animal on one hand and the limit between the Protist and the Plant on the other.

This difficulty is not to be wondered at ; it is what we ought to expect when we consider that all animals and plants are alike constructed of the same material, protoplasm, and that it is upon the activities of this one substance that all the vital processes of animal and plant are dependent.

As a basis of classification we recognise that individual plants and animals may be grouped into a number of SPECIES the members of which closely resemble one another in struc-

ture and are so closely related that it might be assumed that they arose from not very remote common ancestors. Thus Horses, Men, Dogs, Cats, Tigers, the Orange, Apple and Potato Plant form so many species.

The Tiger, the Lion, the Leopard and the Domestic Cat are four distinct species which closely agree with one another in the main characters of their structure.

They all have retractile claws. Their bones and teeth are of the same number and pattern. Their internal organs are all on the same plan. They are all "Cat-like" and only differ in details such as colour, size, arrangement of hair, etc. Such a group of closely related species is called a GENUS.

In like manner the Dog-like species, the Dog, Wolf, Jackal and Fox are grouped into the genus Canis.

In scientific language each animal and plant is given a double name, the first, always written with a capital letter, indicates the genus, the second written with a small letter, the species. Thus the Cat-like animals belong to the genus, *Felis*. The house cat is called *Felis domestica* ; the Lion, *Felis leo* ; the Leopard, *Felis pardus*.

The domestic dog is *Canis familiaris* ; the Wolf, *C. lupus* ; the Jackal, *C. aureus*, the Fox, *C. vulpes*.

Among plants the Orange, Lemon and Mandarin are all species of one genus, *Citrus*. They are called *C. aurantium*, *C. medica*, *C. nobilis*, respectively.

Closely allied genera are grouped into FAMILIES, very often named by adding the termination "idae" (from the Greek *oidos*, like) to the name of the most prominent or familiar genus.

Thus the Cat-like family including all the genus *Felis* and the Hunting Cheetah, *Cynaelurus jubatus*, is called the *Felidae*.

The Mongoose, Civet, Genet and Meerkat genera are grouped into a family, called after the civet, *Viverra*, the *Viverridae.*

The Hyaenas form a family, *Hyaenidae* ; the Dog-like genera form a family called *Canidae.* Bears form another family, *Ursidae.* Weasels, Badgers and others, the *Mustelidae.*

All these families have at least four well-developed toes furnished with claws on each foot, they have teeth and alimentary organs suited for flesh eating. They are thus clearly separated by anatomical structure from the Horse, Ox, Deer and Pig families, all standing on their terminal phalanges encased in horny hoofs, all having their teeth and internal organs adapted to a vegetable diet. We group all such allied families into ORDERS. The flesh eaters are known as the *Carnivora* ; the Horse, Cattle, Deer and Pig families as the order *Ungulata.*

The orders are collected into CLASSES, the classes into PHYLA or SUB-KINGDOMS. Thus all the fur-or hair-covered orders agree in suckling their young and in having warm blood the red corpuscles of which are not nucleated. They form the class *Mammalia.*

Birds, Fishes, Reptiles, and Amphibians form four sufficiently obvious classes which like the Mammalia, all possess either a bony or cartilaginous axial skeleton which surrounds the dorsal nerve-cord. They are therefore classified together as the PHYLUM or SUB-KINGDOM, *Vertebrata.*

We have seen the Phylum of the Protozoa or one-celled animals. The characteristics of three other phyla, the Flat Worms, the Thread-like Worms and the Annulate Worms are given on pages 93 and 94. The characteristics of another

Phylum, the Arthropoda, of which we have studied two classes, the Crustaceae and the Insecta, have been described on page 218.

In the same manner Plants are divided into Phyla, Classes, Natural Orders, etc. Of the Phyla we have studied examples of the Fungi in Bacteria, Yeast and Mucor. Of the Algae which have no differentiation into root, shoot and leaf we saw one example, Spirogyra. Of the Pteridophyta (Gr. *Pteris, pteridos,* fern : *phyta,* plants) we studied the Fern. Of the Phylum of the Flowering Plants we studied Cycas, an example of the Sub-Phylum Gymnosperma, characterised by their naked ovules, and four examples of the Sub-Phylum Angiosperma, of which Maize belongs to the class Monocotyledons ; Bean, Sun-flower and Torenia to the class Dicotyledons.

The likeness between brothers or between individuals of the same species is mainly due to *heredity*. " Like breeds like " is a popular proverb and in the case of an Amoeba or a cell of Spirogyra one can easily understand how, by the parent dividing into equal halves, each of the offspring receives an equal inheritance and almost exactly resembles its parent cell. In the higher animals and plants, however, it is not obvious why the fertilised ova always breed true and develop into organisms resembling their parents in all specific and racial characters. The fertilised ovum of a mouse and that of an elephant are difficult to distinguish from one another, the egg-cell of a sheep, of a goat, or of a woman could not be distinguished from one another by most of us. Yet when fertilised they never develop into the adult of another species.

It is in virtue of the property which we call heredity

that ova always faithfully develop into individuals of the same species as their parents.

On the other hand the most superficial observation will show that no two individuals of a species are alike. On looking round this class *of about two hundred students, all of the genus and species, Man, you see there are no two exactly alike. Selecting two most alike, we find they are brothers. Most of you, solely on the ground of likeness, will be able to divide the class into Parsis, Goanese, Jews, Marathas, English and Hindustanis. A short walk in the streets will show you individuals unmistakably Chinese, Japanese and Sidhis or Negroes.

A very large proportion of the Parsis are relations of one another. Some of you are brothers, others first cousins, second cousins and further distant relations. Goanese are more closely related to one another than to Parsis, Jews, or Hindustanis.

This classification is obviously based on blood-relationship. If we all could produce our pedigrees for some thousands of generations we should probably find that all of us of the Indo-European race are very distant cousins.

We would have to go back very many more generations before we could claim common ancestors with the Chinese, Japanese or Negro.

No one will dispute that likeness in anatomical structure depends upon blood-relationship. The most natural and the most scientific classification of the races present would be to draw up an accurate genealogical tree. As a

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rule the greater the anatomical likeness between races the closer is their blood-relationship and the less remote are their common ancestors. We are all descended from common ancestors ; the different races which we now form have been evolved by the accentuation of anatomical differences technically called variations. Heredity transmits these anatomical differences from generation to generation and tends to keep the various races distinct.

So far we are in agreement with the history and mythology of most countries. The observations of science go further and tend to prove that if we go some millions of years further back we find that all plants and animals of the present day, including Man himself, are descended from common lowly ancestors. The likeness between a Horse and a Donkey or a Zebra is due to blood-relationship. They are all descended from remote common ancestors. They are more closely related to one another than they are to the Cow or Man because in tracing back their genealogical tree we would arrive at an ancestor common to Horse, Donkey and Zebra, much sooner than we could find one common to them, to the Cow and to Man.

The only scientific basis for the classification of animals or plants is " blood-relationship," and this is to be ascertained by the study of their genealogical tree,—their *phylogeny* or the history of their race. We use the term, phylogeny, to indicate the genealogical history of a species, the history of its evolution in its presumed descent from the most lowly ancestral organism up to the condition in which we find the species to-day.

The term, *ontogeny*, is often used to indicate the life-history of an individual, the series of changes through which

the individual organism passes in its development from the ovum to maturity and on to death.

The greater the difference in anatomical structure between any two animals or plants, the more remote is their common ancestor.

Origin of Species, Evolution.
Heredity, Variation, Natural Selection.

The planet on which we live is constantly cooling as it radiates out more heat than it receives from the sun and other heavenly bodies.

Mathematical calculation will therefore prove that at some long distant period the Earth must have been in a molten state and for millions of subsequent years so hot that no animal or plant could possibly have existed. Any protoplasm would have burned or coagulated; life was impossible.

How living organisms first appeared on the Earth, science cannot tell. In the previous chapters we have seen that there is in our day no evidence of spontaneous generation of animal or plant, and that statements to the contrary are based on errors of observation. All existing animals and plants are the offspring of previously existing parents.

The distribution of land and water upon the surface of the Earth is not the same now as it was in past ages. Continents that are now dry were at one time seas, parts that are to-day seas were formerly land.

The chief agent in this change, removing land from one place and depositing it in another is water. Erosion of the coast-line by the tides and waves of the sea is familiar to all. Many of you have seen mighty rivers such as the Indus, the

Ganges or the Brahmaputra in flood sweeping huge banyans, bamboos and buffaloes, as well as smaller plants and animals, onward in their muddy waters to the sea, on the bottom of which the solids are deposited as a sediment. The harder parts of animals and plants such as shells, bones, and woody structures become embedded in the mud and in the course of time some of them will be found as fossils. Occasionally under favourable circumstances the print or impression of softer organisms is taken by the plastic mud, which subsequently hardening, will preserve their picture for future ages.

The sediment of this year lies on top of that of last year, and in its turn will be covered by that of next year. So that in the course of ages we find the estuaries of rivers silted up by mud which has been deposited in layers or strata like the leaves of a book.

The same process has gone on for ages, for millions of years, and it is obvious that, making allowance for disturbances such as earthquakes, volcanoes and other slower twisting and tilting agencies, the upper strata are the most recent, the lower the older.

In the more recent strata we find the remains or fossils of plants and animals almost the same as those living at the present day, but the deeper we go we find them differing more and more, the most striking difference consisting in the absence of the more highly organised. In the deepest, that is, the oldest, strata we get only the most " primitive " organisms, and as we ascend we find newer and more highly organised animals and plants gradually appear. We are forced to conclude either that the higher organisms have been evolved from the lower, or that there has been a succes-

sion of specific acts of creation of higher organisms accompanied by the extinction of many older forms at intervals throughout the ages. We do not believe in the spontaneous generation of the lowest, much less can we credit the spontaneous generation of the highest organisms. All reasoning men are therefore obliged to accept the theory of evolution, to explain the present diversity of animals and plants on the surface of the Earth.

Among biologists this is universally accepted, but as to the causes which have effected this evolution and their relative importance there is a considerable diversity of opinion.

In the beginning of the last century most Biologists followed the teaching of Hebrew mythology that some six thousand years ago the Creator by a miraculous act dumped each separate species of plant and animal, ready-made on the surface of the Earth ; that all the individuals of every species existing to-day are descended from an individual or a pair of individuals suddenly formed at that specific act and epoch of Creation, resembling their descendants of to-day in all essential points of structure.

This legend taught that on the third day after the Earth and the Heavens were created, the Earth, which till then was without life, " brought forth grass and herb yielding seed according to its species, and the tree yielding fruit whose seed was within according to its species." On the 5th day were " created great whales and every living creature which the waters brought forth abundantly according to their species, and every winged fowl according to its species." On the 6th day " were created the beast of the Earth according to its species and cattle according to their species and

everything that creepeth upon the Earth according to its species."

Belief in the immutability of species had become shaken among a few thinking men when Lamarck in 1809 published his "Philosophie Zoologique." He taught that existing plants and animals are descended and have been produced by *evolution* from other species existing at earlier periods. The agency which he believed caused this evolution was the gradual change in environment and the effects of increased use or disuse of different organs. He believed that the modifications caused by environment are transmitted by heredity and increase and accumulate from generation to generation. Thus the whale-bone whale had no hind-limbs because for generations it had ceased to use them; it had no teeth because it had developed the habit of swallowing without chewing; the giraffe had gained its long neck through stretching it for generations; the Negro had developed a black skin through the progressive sun-burning of the skin of many ancestors.

He was a firm believer in the inheritance of what are often called "acquired characters," *i.e.*, those which arise from the relative use or disuse of an organ or from any other effects of the environment upon the organism, in contrast with those which arise from the innate constitution of the germ-cell.

In 1859 Darwin published his great work "The Origin of Species" in which he maintained that "Natural Selection" was the chief agent in the evolution of the higher organisms, plant or animal, in the course of ages from the lower and more primitive.

Though organisms tend to resemble their parents in virtue of the property known as *heredity* it is seldom that any two individuals are exactly alike. The offspring tends to vary in slight details from its parents or from the average of its species. This tendency is called *variation.* The variations, which are slight at first may be transmitted by heredity and may become accentuated in the course of generations.

Darwin pointed out that there is a constant struggle for existence amongst living organisms as they multiply rapidly while the accommodation and food supply are limited. The environment may change from time to time and render the struggle more keen. Under such circumstances organisms possessing suitable variations are able to adapt themselves to the environment and tend to survive. The less gifted individuals are handicapped in the struggle and tend to perish. Nature, as it were, secures the survival of the fittest and an elimination of the unfit ; hence the term " natural selection."

Variation, and natural selection are important factors in the origin of species and the evolution of higher organisms from the lower. When an organism with suitable variations survives in the struggle for existence and the variations become accentuated in the course of generations a type is formed with characters sufficiently distinct to be recognised as a new species.

Darwin pointed out that human or artificial selection had succeeded in producing many varieties or races of domestic animals and cultivated plants. For instance, the cauliflower, broccoli, kohl-rabi, Brussels-sprouts, red and green cabbage have all been evolved by the selection of gardeners from one species of Brassica within historic times. The

Pouter, the Tumbler, the Fantail, the Nun and the Carrier Pigeon have been evolved by human selection from the wild Rock Pigeon.

On the Bombay race-course, you will find three distinct breeds of horse which you can readily distinguish at a glance. You recognise the Arab, the English and the "Waler." You know it is impossible to frame races in which the Arab can successfully compete with the others. You find the English and Waler horse averaging 63 inches in height, the Arab, about 55. Nevertheless the English thoroughbred race horses of to-day are all descended from a few Arab ponies imported into England less than three hundred years ago. By selecting from generation to generation for breeding purposes, the largest or those proved by contest on the race-course to be the swiftest, and by eliminating from the stud the smaller, the weaker and the slower, the breeder has succeeded in artificially evolving a new race of animal.

In nature a similar process of selection is constantly but more slowly producing new races and new species. A variety is but an incipient species ; a species is only a relatively permanent variety.

A little consideration will show the enormous waste of life on the surface of the earth. We have seen that Panulirus produces about a lakh of eggs each year. If all these eggs were to be fertilised and to develop into adult animals, a pair of Panuliri would be represented by a lakh next year and if these reach maturity in four years' time, we would have 100,000 × 100,000 or ten thousand million grand children. In ten years' time the whole sea would become solid with

Panuliri. It is said the Cod-fish produces some eight million eggs. The common human tape-worm of India lays some millions of eggs, but yet the number of tape-worms, of Cod-fish or of Panuliri at the present day is not much greater than it was twenty years ago. If each man and woman on the earth were to produce a family of five and each pair of these in turn were to survive to the age of thirty, and similarly produce families of five,—not by any means an excessive or unusual number,—by the year 2800 A. D. there would be four human beings to each square yard of land. There would not be standing room. Long before this climax the struggle for existence, want of room, want of food, the disguised blessings of war and famine, plague, tuberculosis, cholera, malaria, sexual jealousy and other factors would have thinned out the population to a number adapted to its environment.

On the earth there are too many animal and vegetable candidates for the limited amount of food and space available. There is a constant struggle for existence in this vast slaughter-house, the Earth. Each morning at your breakfast you devour and destroy some hundreds of potential wheat or rice plants.

In this struggle the weakest must go to the wall. Those which are fittest for the struggle by reason of special qualification will survive and hand on the struggle to their offspring. By reason of heredity those of the offspring which have inherited in an accentuated degree the special variations which adapted their parents to their environment will in turn survive and multiply. Those in whom this advanta-

geous variation is absent or poorly developed will fail and perish in the struggle.

In this way success in the struggle with the environment, *natural selection*, will have the same effect we have seen result from artificial selection in the case of the horse, pigeon, etc., and accentuate the useful variations in a species till at last we recognise two or more new species derived from the original one.

We can imagine a carnivorous animal quite different in many respects from the Tiger or the Wolf of to-day, preying millions of years ago on graminivorous animals, common ancestors of the Horse, Bison and Antelope of to-day.

Some of these animals would be swifter than others, some would be stronger than others or provided with better weapons of offence and defence in the way of teeth, horns, etc.

Those that were most swift would be the most likely to survive by flight. Those that were strongest and possessed the best horns could defend themselves best by fight, while the mediocrity, which possessed neither speed nor fighting powers would perish leaving the others to propagate offspring. Of the offspring those with the best running legs and those with the best fighting horns and muscles would survive; the less specialised would perish. In this way Darwin conceived the Antelope and the Bison could be evolved from common ancestors. In similar fashion, the Tiger would evolve strength and bulk while the Wolf would differentiate limbs adapted to running down his prey by long and steady pursuit.

Natural selection explains the adaptability of animals and plants to their environment which is one of their most striking characteristics.

The evidence offered in support of the theory that acquired characters are transmitted is very weak; most of the examples quoted can be better explained by other theories.

For instance; it is a fact that changes in the eye resulting in defective vision can be acquired in the individual as a result of excessive use in reading and writing small and difficult characters.

It is also a fact that a much larger proportion of Parsis have defects of vision obliging them to wear glasses, than have the other races of India. Defective sight is rare among the Pathans, Bhils and Hill Tribes who do little reading or writing but much hunting and fighting.

Parsis have been engaged for many generations as clerks, accountants, jewellers and many of them have injured their sight in such occupations.

Popular belief follows the teaching of Lamarck and attributes the present-day high proportion of young spectacled Parsis to the hereditary transmission of the effects of eye-strain through many generations.

The Darwinian on the other hand gives a more satisfactory explanation by natural selection. The Pathan and the Bhil are constantly engaged in pursuits such as fighting and hunting in which good vision is essential for success. The short-sighted Pathan speedily comes to an end in the struggle for life with one of keen vision. The latter survives and transmits his keen vision to his progeny.

The Bhil who cannot see to kill his food will starve. Other things being equal, the Bhil with the acutest vision is the best hunter, the best fed and the most attractive to the females of his tribe who will willingly aid him in the transmission of his sound organs of sight. It is obvious that natural selection has weeded out hereditary defects of the eyes among Bhils and Pathans.

Bad vision among Parsis is due to *natural selection being in abeyance.* The Parsis are a small community who for many generations have lived in peace among more war-like races. They have not been compelled to engage in war or dangerous sports necessitating good vision or death as an alternative. A pair of spectacles may make a short-sighter clerk a winner in a competition for a clerskship, though they would be a severe handicap in a hand-to-hand struggle for life.

One of the most commonly used arguments against evolution is that the transitional forms in the phylogenic evolution of a species no longer exist.

As the struggle for existence is most acute between similar organisms this is what natural selection would lead us to expect. Similar organisms have similar needs: those endowed with new and better adaptations for the competition of life must necessarily prevail over those less gifted or specialised, and bring about their extermination.

Darwin attached much importance to the gradual accumulation and accentuation of slight variations in the production of new species. He also drew attention to the occasional sudden appearance of "sports" or striking variations which are sometimes handed on from generation to generation.

Of recent years some biologists headed by DeVries, have decried the effect of slight, which they call, "fluctuating," variations. They attach greater value to sudden variations or "sports" which they call "mutations." According to DeVries a new species may suddenly arise already sharply distinguished from its parent by a mutation, in which case we have no intermediate forms to become extinct.

It is difficult to draw the line between a fluctuation and a mutation as permanence is only to be proved by time. Between a large and a small variation there is only a difference of degree. DeVries attached great importance to several distinct new races of the Evening Primrose which he grew from the seeds of plants he found in some waste ground near Amsterdam. He fails to emphasise the facts that this plant is particularly liable to hybridisation, and that he did not know its history beyond that it had "strayed from a neighbouring garden." In the light of these facts it is possible he was dealing with a hybrid splitting up into its Mendelian constituents.

In the lowest geological strata in which we find fossil remains of plants these consist of a few sea-weeds only. It is obvious there cannot have been any of the higher vascular plants in existence for the hard and woody portions of these would certainly have been preserved under conditions in which traces of soft parenchymatous sea-weeds have survived.

We next come upon plants of the Fern phylum ages before any of the Flowering Plants appear. It was for some time a staple argument against the theory of evolution that there was a great and unbridgeable gap between the Cryptogam and the Flowering Plant. You have already seen

how Cycas, in its habit like a Tree Fern, and above all in its motile spermatozoids, provides the " Missing Link " in its ontogenic features. There was a time when plant life on the dry earth almost entirely consisted of Ferns, including many giant ancestors of our present Horsetails, some of which at least, produced both microspores and megaspores.

Later, as already related, Cycads formed the main forest growth. In between the Age of Ferns and the Age of Cycads and overlapping both ages, there appeared plants embodying so many of the features common to both Ferns and Cycads that geologists and botanists alike were so puzzled as to their status that they called them " Cycadofilices " and " Pteridosperma " (Gr. Fern-seed-plants), Fern-like plants bearing seeds which the systematists teach us are the monopoly, the most striking and universal feature of the Flowering Plant.

The giant Horsetails, the non-descript Cycadofilices and Seed-Ferns have died out, unable to compete with the Fern already well adapted to its environment and the Flowering Plant specially organised for the struggle for existence.

The Cycad was followed by higher Gymnosperms resembling the Pines and Deodars of to-day. Lastly the Angiosperm, the most highly differentiated of plants, made its appearance. As far as plants are concerned their phylogeny, as written in the Rocks is a clear history of Evolution from the lowest to the highest.

The original five-toed or pentadactyl (Gr. *penta*, five ; *dactylon*, toe) type of limb which we saw in the Frog continues with certain modifications in all the higher Vertebrates.

Man, notwithstanding the great physiological development of the hand as an organ of prehension, retains the five-

digit type of limb in a comparatively primitive morpholo-gical condition. In the hoofed mammals we find a gradual reduction in the number of digits, accompanied by an uplift-ing of the heel till at last the animal stands on the extreme tip of the toes, instead of resting on the whole sole as do the Frog, Rabbit and Man. Hence, in animals such as the Horse and the Cow, the heel is situated at the middle of the hind-leg and is known as the "hock;" similarly the wrist is in the middle of the length of the fore-limb and is popularly called the "knee."

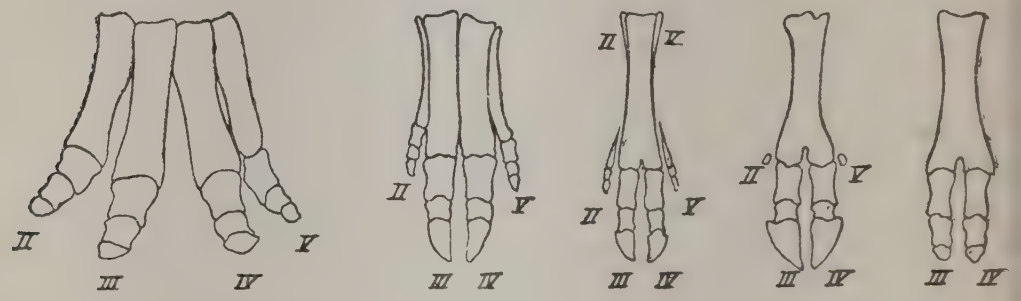

Fig. 139.—*Left fore-feet of even-toed Ungulates—from left to right Hippo-potamus, Pig, Deer, Ox and Camel. The numbers indicate which of the normal five digits are present in each foot.*

In the even-toed Ungulates we find this reduction gradual; the Hippopotamus, the oldest in a phylogenic sense, has four well-developed digits, all four resting on the ground; the Pig has four digits but only two reach the ground; the Deer has the two lateral digits still further reduced and firmly ankylosed with the middle two metacarpal bones; in the Sheep and the Cow the second and fifth digits are reduced to mere nodules of bone, while in the Camel all trace of the lateral digits has disappeared. In the Deer, Cow and Camel the third and fourth meta-carpals are completely united to form one bone. These

structural modifications are obviously correlated with adaptation to successive changes of environment from river and mud to swamp, jungle, open plain and sandy desert.

In the odd-toed Ungulates we find a similar progressive reduction. The Tapirs stand on three toes; the hind-limb has only three toes; although the fore-limb has four, the inner toe does not reach the ground. In the Rhinoceros the second, third and fourth toes are about equally developed. In the Horse we find there is only a single toe, the third, in each foot with only vestiges of the second and fourth metacarpals ("splint bones") which have become not only functionless but frequent sources of disease, as is common in such vestiges.

We have traced the phylogeny of the "Thoroughbred" Horse as influenced by artificial selection in the past three hundred years from the Arab pony. Nature has preserved a fossil stud-book in which we can trace his genealogy for probably five million years up to a tapir-like ancestor less than a foot in height.

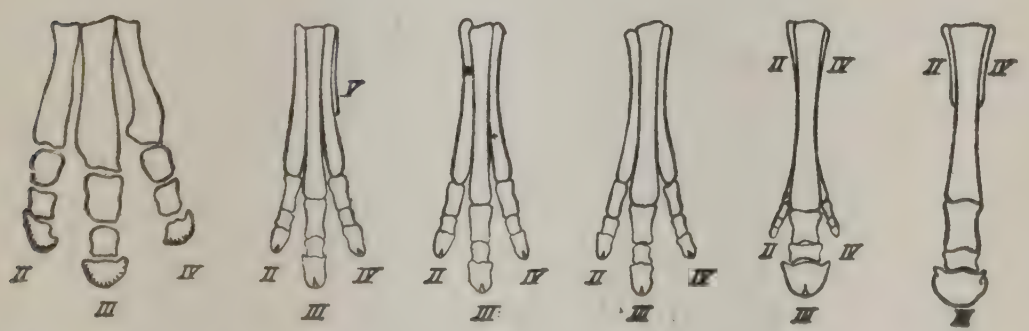

Fig. 140.—*Left hind-feet of odd-toed Ungulates—from left to right Tapir, Eohippus, Orohippus, Mesohippus, Neohipparion and the Horse. The numbers indicate which of the normal five toes are present in each foot.*

Fossil remains of the primitive horse, Eohippus, show that he was about ten inches high and possessed four well-developed toes with a " splint bone " remnant of the thumb in the fore-limb. In the hind-limb he had three well-developed and separate toes, but there is no trace of the great toe and only a splint bone to represent the fifth.

In later strata we find a Horse about 18 inches high, who has lost the fifth toe splint and has only three digits in the hind-leg. In the fore-leg the thumb has completely disappeared and only a splint represents the fifth digit.

Later we find fossils of several extinct genera which are all three-toed but the lateral toes are all greatly reduced.

Later still we find the one-toed Horse making his appearance both in America and in the old world where for some time a three-toed cousin survived as a contemporary.

RECAPITULATION IN THE INDIVIDUAL OF ANCESTRAL CHARACTERS.

In our study of the embryology of the higher animals and plants we have drawn attention to the fact that the life-history of the individual organism is in many respects an epitome of its phylogeny,—the ancestral history of the species. All the higher animals and plants begin their life as a fertilized ovum,—a one-celled organism resembling the Protozoan Amœba. The ovum, by repeated fission, in most animals comes to form a ball of many cells—a morula. This later becomes hollow and its wall gets pushed in at one pole, further and further till we get a two-walled *gastrula* resembling Hydra.

In the higher Vertebrates, including Man himself, the heart originates as a simple dorsal tube like that of the Earth-worm. At one period in his mother's womb each individual Man possesses gill-clefts on each side of his neck like the Tadpole and all Fishes. Seven months before birth each Man's vertebræ project well behind his buttocks to form a well-marked tail. Some months before birth the whole of Man's skin with the exception of the palms and soles is covered with a fine fur.

The theory of Specific Creation can offer no help in explaining these facts. It is impossible to imagine a Creator capable of forming only a single plan or of adhering rigidly to many of its details when they are not only utterly useless but in many cases actually harmful to His creatures.

On the Evolution theory we do not wonder that the individual organism repeats in its own life-history the history of its ancestors. An organism inherits not only the characters of its immediate parents but also those of many remote ancestors. We may therefore expect the embryo to inherit the characters of its ancestors in the order in which they appeared in the evolution of the species.

WEISMANN'S THEORY OF THE CONTINUITY OF THE GERM SUBSTANCE, MENDEL'S OBSERVATIONS AND LAW.

The phenomena of heredity in multicellular animals and plants must depend on some content of the germ cells. To this substance Weismann gives the name "*germ-plasm*," and identifies it with the chromatin of the germ cells.

He lays much stress on the distinction between the body or "somatic" cells and the "germ" cells. The soma-

tic cells of higher plants and animals vary much in shape and function and build up the body of the individual animal or plant.

The germ cells, on the contrary, have little to do in the life of the individual which supports and protects them. Their destination is, under favourable circumstances, to give birth to a new generation. The soma produces nothing, it nourishes itself and the germ cells; grows to the adult stage and dies. The germ cells produce the soma or individual animal and at the same time the new generation of germ cells (Fig. 141).

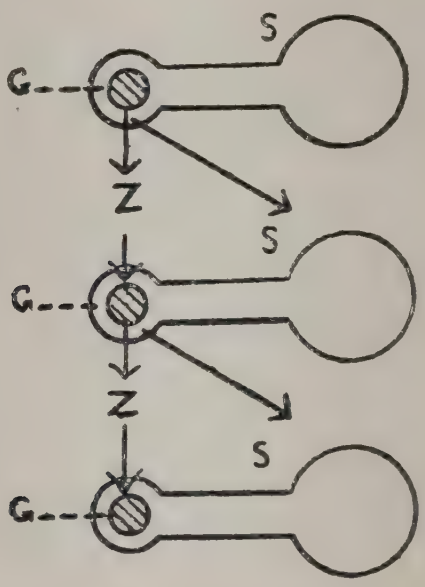

Fig. 141.—*Diagram to illustrate the continuity of the germ-plasm from generation to generation.*

G.—Germ-plasm. S.—Soma. Z.—Zygote.

Weismann maintains that the germ cells are segregated from the somatic cells at a very early stage in the development of each individual. It is true that this differentiation can be recognised at such an early stage as the first division

of the zygote in the case of the round worm parasitic in the horse, but this is very exceptional, segregation of the germ cells usually takes place at a much later stage of development in most organisms. Notwithstanding this we may assume that each germ cell contains a complete sample of the hereditary germ plasm.

Were Weismann's theory correct we would have no difficulty in understanding how the germ cells form a continuous chain from generation to generation, like protozoa, and so breed true. We could also easily believe that no characters acquired by the soma would become hereditary, as they could have no effect on the germ cells beyond perhaps influencing their nutrition.

The theory gives a rational explanation of the phenomena of karyokinesis, maturation of germ cells and fertilisation. Karyokinesis can be regarded as a mechanism for apportioning to each daughter cell an equal amount of chromatin, that is, an equal share of ancestral characters. The resemblance of the offspring to both parents is brought about by reduction of the chromosomes in the gametes and restoration of the somatic number in the zygote by conjugation. Since it is probably a matter of chance as to which characters are lost in the process of reduction and which are added at the time of fertilisation, the phenomena of maturation and union of gametes provide the mechanism for the production of variations.

Mendel's discovery of the laws regarding hybrid plants emphasises the importance of the chromatin as the carrier of hereditary characters.

Sixty years ago the Abbe Mendel, while conducting some observations on cross-breeding between certain races of plants, took two varieties of the edible Pea, *Pisum sativum*, one of which was constantly tall, between six and seven feet in height, the other constantly dwarf, between nine and eighteen inches. Under normal conditions the Pea is a self-fertilised plant, so he had little difficulty in producing hybrids by cutting the stamens out of a young flower and dusting its stigma with pollen obtained from a plant of the opposite character as regards height. Contrary to his expectation the cross-bred plants, instead of being of medium height, 3 to 4 feet, were all tall. On collecting and sowing all the seeds of this first hybrid generation he was further surprised to find the resulting second hybrid generation were one-quarter dwarf, three-quarters tall ; there were no intermediate heights.

He further found that while the seeds of the 25 per cent. dwarf plants of this generation all bred true, giving rise to dwarfs only, the 75 per cent. tall were of two kinds, one-third gave rise to pure talls, while two-thirds again gave rise to talls and dwarfs in the proportion of 3 to 1.

He also crossed two races, the seeds of one being green, of the other bright yellow. The resulting hybrids of the first generation, which for the sake of brevity we will call F 1, all bore green seeds. Of the second generation of hybrids, F 2, 75 per cent. bore green seeds, 25 per cent. yellow. The yellow seeds of F 2 gave rise exclusively to yellow-seeded plants in F 3 generation. One-third of the green seeds of F 2 gave rise to all green seeds in F 3 while the plants resulting from the remaining two-thirds of the green

seeds of F 2 gave rise to green-and yellow-seeded plants in the proportion of 3 to 1, exactly as all the seeds of F 1 had done.

Mendel found that in the process of crossing, many other contrasting "unit" or "differentiating" characters such as tallness × shortness; green colour of seeds × yellow colour of seeds; smooth coat of seeds × wrinkled coat, etc., behaved in the same way. Instead of an intermediate character appearing in the first hybrid generation, F 1, one of the contrasting "unit characters" was completely suppressed, all the offspring exhibiting the opposite character; while F 2 the offspring of the first generation of hybrids were in the proportion of 3 resembling F 1, to 1 showing the suppressed character.

To the suppressed characters he gave the name of *recessive* which we will indicate by the letter R. To the opposite character, that which asserts itself in the first hybrid generation, he gave the name *dominant* which for brevity's sake we indicate by the letter D.

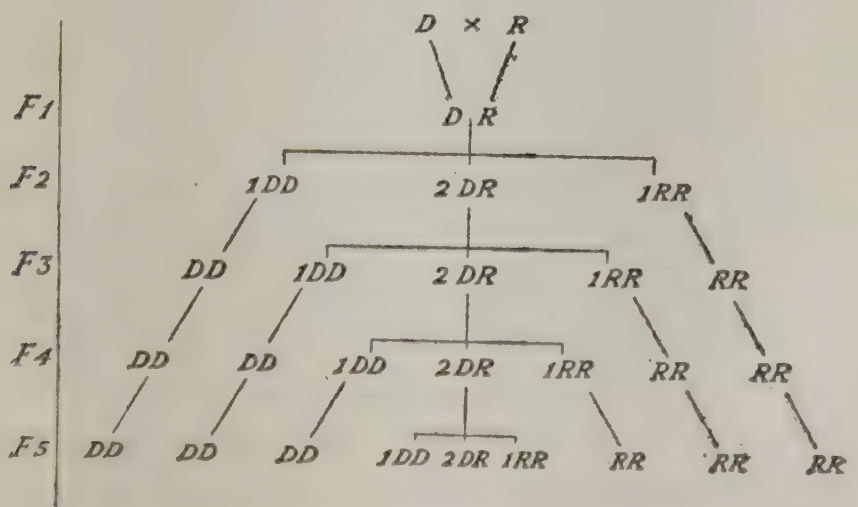

Fig. 142.—*Diagram illustrating Mendel's Law.*

A case in which the dominant factor in the hybrids still leaves a slightly intermediate character in the genuine hybrid D. R., by which it can be distinguished from D. D., the pure dominant, in the hybrid generation is very helpful in demonstrating the Mendelian results.

If a white-flowered *Mirabilis jalapa*, (*gulbas*), be crossed with a red-flowered individual all the first hybrid generation are red, but this red is of a somewhat pinkish shade which easily distinguishes it from the pure red.

When these pink hybrids are fertilised from one another the resulting generation is in the proportion of 25 per cent. red, 50 per cent. pink, 25 per cent. white ; clearly 1 D. D. : 2 D. R. : 1 R. R. All the reds of this generation will give rise to pure reds only ; all the whites to pure whites only ; while the 50 per cent. pinks will, as before, give rise to 25 per cent. pure red, 25 per cent. pure white and 50 per cent. hybrid pink.

As an explanation of these phenomena Mendel offered the very simple and satisfactory theory, that *the gametes of the hybrid generation are not themselves hybrid but pure for each pair of unit characters*.

If the dominant and recessive gametes be equal in number and their conjugation be promiscuous, it follows from the rule of averages that D. gametes will unite with D., D. with R., and R. with R. in the proportion of 1 : 2 : 1. But we have already proved in the result of the first hybrid generation that whenever D. conjugates with R. the resulting hybrid shows the character of D. Hence the offspring of the second hybrid generation *appear* to be in the proportion of 3 D to 1 R. but of the 3 D. one only is pure D., two are D. R.

As suggested by Professor Thomson the student can illustrate this result by shaking up an equal number of black and white draughts men in a bag to represent so many F. 1 gametes and then withdrawing them two and two without selection. We will assume that the black draughtsmen are " dominant " to the " recessive " white. Each pair withdrawn will represent a zygote. The dominant character we will place on top of the recessive. In a sufficiently large number of trials you will find that you will draw an average percentage of 25 pairs of white, 25 pairs of black and 50 " hybrids " or pairs of black and white. But if you put the " dominant " black on top of the " recessive " white, the appearance you obtain when looking from directly above is 75 pairs black, 25 pairs white. Further investigation shows you that of the 75 pairs black only 25 are pure black, 50 pairs are " hybrid." Altogether we have 25 D. D., 50 D. R., 25 R. R., that is, the true Mendelian ratio of 1 D. D : 2 D. R. : 1 R. R.

The only possible explanation of these phenomena is that each individual is produced by two gametes. (*a*) Each gamete contains only one of the two contrasting characters length, shortness, etc. (*b*) The two kinds of gametes, *i.e*, those conferring length and those conferring shortness are equal in numbers. (*c*) The gametes conjugate at random. Therefore in accordance with the law of averages we may expect to get offspring in the proportion of 1 D. D. : 2 D R. : 1 R. R. exactly as Mendel obtained.

The explanation is further simplified when we note that almost all contrasting characters which obey the Mendelian

law consist of a positive dominant and a negative recessive, *i.e.*, dominance is due to the *presence* of a definite or positive factor while recession is due to the *absence* of that factor. In the above experiments the dominant character tallness, in the case of the Pea, is the presence of length ; the recessive shortness is merely absence of length ; the dominant green is due to the presence of chlorophyll in the seed coat, the recessive yellow to its absence. In the case of *gulbas* the dominant red is due to the presence of the colour red ; the recessive whiteness is merely absence of colour. We might almost substitute the sign *plus* + for D. and *minus*—for R.

INDEX GLOSSARY.

Abbreviations. Gr. = Greek, Lat. = Latin. pl. = Plural.

Pronounce ĕ. short, as in " bet." œ. and ē. long, as in " teeth," ĭ. short, as in " hit." ī. long, either as in " light," or as ee in " qüeen." ŏ. short, as in " hot." ō. long, as in " hole." ŭ. short, as in " hut." ū, long, as in " rude."

In Greek words, we have written " u " as " y," " gg, etc.," as " ng, etc." to simplify matters for Indian students.

Abdōmen. (Lat. belly). Cockroach. 144. Mosquito. 180. Panulirus. 99.

Abducens. (Lat. *ab*, from ; *duco*, to draw). The sixth cranial nerve which supplies the abductor muscle of the eye-ball. 364.

Aberrant. (Lat. *aberrans*, wandering from, deviating). Varying from the normal type.

Abīogenesis. (Gr. *a*, not ; *bios*, life ; *genesis*, origin, development). The doctrine formerly held that organisms could arise from non-living matter, " spontaneous generation." 6.

Abortive. (Lat. *abortus*, miscarriage, born prematurely). A term to indicate an organ is poorly developed.

Acetabulum. (Lat. a cup for vinegar). The socket in the pelvic girdle with which the head of the femur articulates. 324.

Acœlous. (Gr. *a*, without ; *koilos*, hollow). A term applied to vertebræ the centra of which are not hollow at either end. 320.

Adrenal body. (Lat. *ad*, to ; *ren*, the kidney). A ductless gland lying close to the kidney. 347.

Aelosōma. A primitive species of Oligochaete. 88.

Albumen. (Lat. *albus*, white). A term loosely applied to proteids generally. The substance secreted by the oviduct and forming a coating round the ovum. 352.

Alécithal. (Gr. *a*, without ; *lekithos*, yolk). Yolk-less. Applied to eggs that contain little yolk.

Algæ. (Lat. Sea-weeds). The phylum of plants, whose body is a permanent thallus, containing chloroplasts.

Alternation of Generations. 46, 227, 257.

Amœba. (Gr. *amoibos*, changing). 1.

Amphibia. (Gr. *amphi*, both ; *bios*, life). Animals which at first breathe by gills and lead an aquatic life, later breathe by lungs and lead a terrestrial life. 309.

Amphicœlous. (Gr. *amphi*, both ; *koilos*, hollow). A term applied to vertebræ the centra of which are hollow at both ends. 320.

Amphioxus. (Gr. *amphi*, both ; *oxus*, sharp). The Lancelet. A little marine animal tapered at both ends possessing a notochord but no vertebral column or brain. 355.

Ampulla. (Lat. a flask). The dilated end of the semicircular canal. 368.

Anabŏlism. (Gr. *anabole*, anything built up). Constructive metabolism. 7.

Anal spot. 30.

Anastŏmōsis. (Gr. *anastomoo*, to open into). Inosculating or uniting and opening into one another as do arteries and veins. 165.

Androœcium. (Gr. *aner, andros*, man, male ; *oikos*, house : " the men's house "). The collective name for the male sporophylls in a flower. 247.

Anemophilous. (Gr. *anemos*, wind ; *philao*, to love). Wind-loving. Applied to flowers pollinated by the wind. 251.

Angiosperms. (Gr. *angion*, vessel or case ; *sperma*, seed). The group of flowering plants which have their seeds enclosed in the carpel. 240.

Angulosplenial. (Lat. *angulus*, a corner, Gr. *splenion*, a splint). 318.

Annĕlīda. (Lat. *annellus*, a little ring). The phylum of worms, whose bodies are composed of a number of ring-like somites, without limbs. 95.

Annulus. (Lat. a ring). 223.

Anōphĕlēs. (Gr. hurtful). A genus of mosquitoes. 171.

Anopheline. Belonging to the Sub-family Anophelina. 171.

Antenna. (Lat. the sail-yard of a ship). 116, 149, 171, 173.

Antennule. (Lat. a small sail-yard). 117.

Anther. (Gr. *antheros*, flowery). That part of the stamen which consists of pollen-sacs. 247.

Antheridium. A name given to the male gonads of Ferns, Mosses and some of the lower plants. 204.

Antherozoids. The same as spermatozoids. 206, 207.

Antipodal cells, Cells at the " Antipodes " of the megaspore, *i.e.*, farthest from the egg-apparatus. 251.

Aortic arch. The systemic arch. 334.

Apical cell. 217.

Apical meristem. 217, 279, 299.

Apocarpous. (Gr. *apo*, apart). Term used to indicate that the carpels which compose a pistil are free from one another.

Apodēme. (Gr. *apodaio*, partition). A process of the cuticle directed inwards in Arthropods to form an endoskeleton. 99, 146, 148.

Appendages. Panulirus, 101. Cockroach, 147. Mosquito, 173.

Aqueous. (Lat. *aqua*, water). Aqueous chamber, humour. 367.

Arachnoid. Like a spider's web. (Gr. *arachne*, spider ; *oidos*, like). The middle of the three membranes investing the brain and spinal cord. 362.

Archegōnium. (Gr. *arche*, primitive, beginning ; *gone*, seed, or womb). The female gonad of Mosses, Ferns and flowering plants. 205.

Archenteron. (Gr. *arche*, primitive ; *enteron*, gut). The primitive gut lined by hypoblast in the embryo, which subsequently becomes the mid-gut. 137, 376.

Artery. (Gr. and Lat. *arteria*, artery or air pipe). A vessel which carries blood from the heart as opposed to veins which bring it to the heart. 119, 341.

Arthrobranchia. (Gr. *arthron* joint ; *branchia*, gills). Gills attached to joint membranes. 107.

Aspidium. (Gr. *aspides*, shield-like). The genus of Shield Ferns. 210.

Assimilation. The conversion of food materials into protoplasm. In green plants specially used as a synonym for photosynthesis, the assimilation of carbon dioxide. 20.

Astragalus. (Gr. *astragalos*, ankle-bone). A bone in the proximal row of the tarsus. 324.

Atlas. (Gr. the god who holds up the globe). The human skull being globe-shaped, the vertebra on which it rests was named the atlas by the ancients. 320.

Atrophy. (Gr. *a*, negative ; *trophe*, nourishment). Wasting away, 110.

Auditory nerve. The eighth cranial nerve. 364.

Auricle. (Lat. diminutive of *auris*, the ear). The external ear of Mammals. A chamber of the heart, in Man shaped like a dog's ear. 337.

Axil. (Lat. *axilla*, armpit). The angle formed by a leaf with the portion of stem above its insertion. 265.

Bacillus. (Lat. a little stick). A rod-shaped bacterium. 6, 52.

Bactēria. (Gr. *bakterion*, a small rod). Unicellular plants of microscopic size belonging to the group of Fission Fungi. 6, 48.

Basipodite. (Gr. *basis*, base ; *pous, podos*, foot). The distal piece of the protopodite, to which are attached the endopodite and exopodite. 102.

Bean. 240, 258.

Bile. A fluid secreted by the liver. 344.

Biogenēsis. (Gr. *bios*, life ; *genesis*, origin). The theory, that all organisms must arise from pre-existing parent organisms. 6.

Biramous. (Lat. *bi*, two ; *ramus*, a branch). Possessing two branches, as the typical Crustacean appendage. 110, 151.

Bladder. 378.

Blastocœle. (Gr. *koilon*, a cavity). The segmentation cavity. The cavity of the blastula. 375.

Blastoderm. (Gr. *blaste*, sprout ; *derma*, skin). In an egg containing much yolk segmentation takes place only in a certain patch or area to which this name is given. 136.

Blastomēre. (Gr. *meros*, a part). The individual cells into which the ovum segments to form the blastula. 63, 375.

Blastopore. The pore or opening into the archenteron caused by the invagination of the blastosphere. 63, 376.

Blastosphere. 375.

Blastula. The hollow ball or mass of cells which results from the morula becoming hollowed out. 63, 375.

Blatta. (Lat.) A genus of cockroaches.
Blood. 1, 80, 341.
Brachial. (Gr. *brachion*, arm). Nerve, 361 ; vein, 331.
Bract. A leaf in the axil of which a flower is developed. 269, 271, 275.
Brain. 88, 129, 163, 353.
Branchia. (Gr.) Gills, 107.
Branchiostegite. (Gr. *tego*, to cover). The gill cover. 105.
Buccal Cavity. (Lat. *bucca*, cheek). The mouth cavity. 27, 78, 313.
Bud of Hydra. 63.
Bulbus arteriosus. The distal part of the truncus arteriosus. 339.
Caecum. (Lat. blind). A blind pouch. 79, 157.
Calcaneum or Os Calcis. (Lat. *calx calcis*, the heel). 324.
Calcar. (Lat. a spur). 324.
Calyx. (Gr. cup). The complete whorl of sepals. 244.
Cambium. (Lat. *cambio*, to change). The layer of meristem between the wood and the bast of " open " bundles from which new wood and bast are formed. 286.
Capillaries. (Lat. *capillaris*, fine as a hair). The smallest blood vessels uniting the arteries and veins. 81, 119.
Carapace. In Crustaceæ the united terga of the head and thorax. 99.
Cardiac. Relating to the heart. 124.
Cardo. (Lat. a hinge). The proximal joint of an Insect's first maxilla. 151.
Carotid arch, artery, plexus. 334.
Carpel. (Gr. *karpos*, a fruit). The female sporophyll of a flowering plant. 233, 247.
Carpopodite. (Gr. *karpos*, wrist). The fifth segment in a Crustacean appendage. 110.
Carpus. (Lat. the wrist). 323.
Cartilage bone. Bone formed by ossification of pre-existing cartilage. 315.
Cauda equina. (Lat. tail of a horse). The bundle of posterior spinal nerves with the filum terminale as they lie in the spinal canal. 361.

Cells. The nucleated pieces of protoplasm of which all animals and plants are built up. 32.

Cell division. 4, 14, 225.

Cellulōse. A carbohydrate substance entering into the composition of most vegetable cell-walls. 12.

Cement gland. 161, 181.

Centrolecithal. (Gr. *lĕkithŏn*, yolk). A term applied to eggs like those of the Arthropoda in which the yolk occupies a central position. 136.

Centrosome. (Gr. *kentron*, centre ; *soma*, body). A minute body in the protoplasm of a cell which becomes prominent when the nucleus is undergoing division.

Centrum. (Lat. centre). The body or ventral portion of a vertebra. 319.

Cephalothorax. (Gr. *kephale*, head). The combined head and thorax of a Crustacean. 99.

Cerebellum. (Lat. diminutive of *cerebrum*). The " little brain." An outgrowth from the dorsal region of the hindbrain. 359.

Cerebral. (Lat. *cerebrum*, the brain). Hemispheres. 356.

Chæta. (Gr. A bristle or seta). 67.

Chætopoda. (Gr. bristle-footed). The class of worms whose a organs of locomotion have bristles imbedded in the skin. 95.

Chalaza. (Gr. a pimple). The part of an ovule where the nucellus and integuments unite. 234, 248.

Chēla. (Gr. *chele*, a claw). The pincers of animals like the Prawns and Lobsters. 113.

Chiasma. (Gr. two lines crossed as in the letter X). 363.

Chitin. Pronounced *Kyteen*. (Gr. *chiton*, tunic, coat of armour). A substance secreted by the epidermal cells of many animals to form a cuticle insoluble in acids or boiling K H O solution. A similar substance may be secreted by Protozoa. 49, 85, 93.

Chlōrophyll. (Gr. *chloros*, green ; *phyllon*, leaf). The green colouring substance of plants. 13, 19.

Chlōroplast. (Gr. *plastos*, moulded, formed). The intracellular bodies in which chlorophyll is contained. 13.

Chordæ tendineæ. (Lat. tendinous chords). 339.

Chordata. The phylum of animals, including Vertebrata, that possess a dorsal chord or axial skeleton. 353.

Choroid. (Gr. *chorion*, skin, membrane ; *oidos*, like). The middle coat of the eye-ball. 366.

Choroid plexus. 357.

Chrōmatin. (Gr. *chrōma*, colour). That portion of the nucleus which can be stained deeply. 225.

Chrōmatŏphōre. (Gr. *phorein*, to carry). The bodies in the cell which contain chlorophyll or other coloring matter. 13.

Chrōmosōmes. (Gr. *chrōma*, color ; *soma*, body). The rods or filaments into which the chromatin collects at the time of division of the nucleus. 225.

Cilium, *pl.* cilia. (Lat. eyelash). Minute threads of protoplasm, which vibrate rhythmically in unison with one another. 28.

Cingulum. (Lat. belt). 71.

Circināte. (Lat. *circinus*, a circular course). Term applied to the arrangement of a leaf in the bud when the apex is coiled up towards the base of the axis as in Ferns. 210, 231.

Class. 386.

Classification, of worms, 94 ; Mosquitoes, 170 ; Principles of, 384, 389.

Clavicle. (Lat. *clavicula*, a little key). 321.

Clipeus or Clypeus. (Lat. a shield). 148.

Clitellum. (Lat. *clitellae*, a saddle). A term applied to the Cingulum of an Earthworm when it does not form a complete ring. 71.

Cloaca. (Lat. a drain or sewer). A chamber into which the intestine and the urinary and genital ducts open. 348.

Cnīdoblast. (Gr. *knīde*, a nettle ; *blaste*, bud). The cell in which the sting of Hydra is formed. 61.

Cnīdocil. (Lat. *cilium*, hair, eyelash). The hair-like process or trigger of a cnidoblast. 61.

Cochlea. (Lat. a snail-shell). An outgrowth from the membranous labyrinth, which has a spiral cavity in the higher Vertebrates, 368.

Cockroach. 141.

Cœlenterata. (Gr. *koilos*, hollow ; *enteron*, gut—a stupid name !). A name given to the Diploblastic animals, the phylum to which Hydra belongs.

Cœliac. (Gr. *koilia*, the belly). Artery. 336.
Cœlomăta. A collective name for all the phyla that possess a cœlome 77.
Coēlōme. (Gr. *koiloma*, a cavity). The space between the two layers of the mesoderm. 76.
Colleterial glands. (Gr. *kolle*, glue, cement). The cement glands of a female insect. 161.
Colloids. (Gr. *kolle*, glue ; *oidos*, like). Substances which cannot diffuse through an organic membrane.
Columella. (Lat. a little column). A projection of the stalk into the gonidangium of Mucor ; often absent. 44, 318.
Commissure. (Lat. *commissura*, a joining together). A transverse nerve band joining two ganglia. 132.
Condyle. (Gr. *kondylos*, a knuckle). 323.
Cone cells. 367.
Conglobate gland. (Lat. *conglobatus*, pressed together). The accessory gland of the male Cockroach. 160.
Conjugation. (Lat. *conjugatio*, sexual intercourse). The union of gametes. 15, 45.
Conjunctiva (Lat. *con*, together ; *jungo*, to join). The membrane lining the front of the eye-ball and the inner surface of the lids. 366.
Connective. A longitudinal nerve strand joining two ganglia, 88.
Contractile vacuole, 4, 28.
Conus arteriosus. The proximal part of the truncus arteriosus. 339.
Coracoid. (Gr. *korax*, a crow ; *oidos*, like). In man the coracoid is not a separate bone and is represented by a process of the scapula somewhat resembling the beak of a crow. 321.
Cornea. (Lat. *corneus*, horny). The transparent anterior part of the sclera. 366.
Cornu. (Lat. a horn. Pl. *cornua*). A projecting process of bone or cartilage. 318.
Corolla. (Lat. a little crown). The whole whorl of petals. 244.
Corpora bigemina. (Lat. twofold bodies). The optic lobes. Two hollow outgrowths from the roof of the mid-brain. 359.
Corpuscles. (Lat. *corpusculum*, a little body or particle). The cellular elements of blood. 1, 80.

Cortex. (Lat. bark). Outer portion. 27, 281.

Costa. (Lat. a rib). The nervure of the anterior margin of an insect's wing. 179.

Cotylēdon. (Gr. cup or socket). The first leaves formed by the embryo flowering plant. 259.

Cŏxa. (Lat. hip). The proximal joint of an Insect's leg. 147, 178.

Cŏxŏpōdīte. The proximal joint of a Crustacean appendage. 101.

Cranial nerves. The nerves arising from the brain. 363.

Cranium. (Gr. *kranion*, the skull). The cartilaginous or bony case which encloses the brain. 316.

Crop. A dilated part of the oesophagus. 157.

Crus cerebri. (Lat. *crus*, *pl.* crura. a leg). Two bands of longitudinal nerve fibres on the floor of the mid-brain. 359.

Cryptogams. (Gr. *kryptos*, *hidden ; gamos*, wedding). The non-flowering plants in which the sexual apparatus is not visible to the naked eye.

Culex. (Lat. mosquito). A genus of mosquitoes. 172.

Culicidae. The whole family of mosquitoes. 172.

Culicina. The sub-family of mosquitoes allied to Culex. 172.

Cutaneous. (Lat. *cutis*, the skin). Pertaining to the skin. Artery. 334.

Cuticle. (Lat. *cuticulus*, the outer skin). The outermost layer of the skin in animals,—secreted by the epidermis in Invertebrates ; the outermost layer of cells in Vertebrates. In higher plants that portion of the outer wall of the epiderm is which is cutinised. 91, 280.

Cutin. The chemical substance which is found in cuticularised cell walls and renders them water-proof. 279.

Cycas. A primitive genus of Gymnosperm. 228.

Cyst. (Gr. *kystos*, bladder, sac).

Cytoplasm. (Gr. *kytos*, cell ; *plasma*, substance). The general mass of protoplasm as distinguished from and excluding the nucleus.

Dactylopodite. Gr. dactylon, finger. The terminal segment of a Crustacean appendage. 110.

Darwin. 133, 393.

Decomposition. 5, 50.

DeVries. 400.

Diadelphous. (Gr. *adelphos*, brother). Term used to indicate that the filaments are united to form two bundles or brotherhoods of stamens. 272.

Diaphragm. (Gr. *diaphragma*, a partition). A muscular partition occurring in Mammals between the cavities of the thorax and abdomen.

Dichŏtŏmous. (Gr. *dichotomia*, dividing or cutting into two).

Diclinous. (Gr. *di*, two : *kline*, bed). Term to indicate the stamens and carpels occupy separate beds, *i.e.*, are on separate flowers or thalami.

Dicotylēdon. (Gr. *kotyledon*, cup). The class of flowering plants that have two cotyledons or seed-leaves. 267.

Didynamous. (Gr. *dynamos*, strength). Term used to indicate that the stamens are in pairs of two different lengths as in Torenia. 273.

Differentiation. The process by which cells or organs originally similar become different in structure. 33.

Dīœcious. (Gr. *di*, *dis*, two ; *oikos*, a house or dwelling). A term to indicate that either the male and female gonads or the sporophylls dwell in separate individuals ; unisexual. 229.

Dĭploblastic. (Gr. *diploos*, double, *blastos*, bud, elementary tissue). Applied to Metazoa whose body is made up of only two cell-layers, ectoderm and endoderm without a mesoderm. 59.

Dĭptĕra. (Gr. *di*, two ; *pteron*, wing). The order of two-winged insects such as Mosquitoes and Flies. 170.

Disc or Bud, Imaginal. 198, 274.

Distal. (The opposite of proximal). Further removed from the axis, or point of attachment to the body.

Divergence. 262.

Division of labour. 33.

Division of nucleus. 225.

Dominant. 410.

Dorsum. (Lat. back.) The upper surface or side away from the ground during progression in animals. That side of a leaf which looks outward from the stem while in the bud.

Ductless glands. Glands without ducts, whose secretion is carried away by the blood. 353.

Duodenum. (Lat. twelve). The first part of the small intestine, named from its length in man being about twelve fingers' breadth. 344.

Dura mater. (Lat. hard mother). A tough fibrous membrane lining the inside of the cranium and neural canal. 362.

Earthworm. 66.

Ecdysis. (Gr. an escape, a putting off). The process of casting off the cuticle: moulting. 100, 117, 140, 166, 195.

Ectoderm. (Gr. *ectos*, outer; *derma*, skin). The outer cell-layer of animals, derived from the epiblast. 58.

Ectoplasm. (Gr. *plasma*, anything moulded). Same as—

Ectosarc. (Gr. *sarx*, flesh). The outer hyaline layer of protoplasm in unicellular organisms. 3, 27.

Egg. Egg-cell. The ovum, female gamete. 16.

Elytra. Plural. (Gr. *elytron*, a cover). A term applied to the anterior wings of insects, when they form a hard cover for the posterior wings.

Embryo. (Gr. *embryon*, a foetus). 258.

Embryology. (Gr. *embryon*, a fœtus; *logos*, science). The science dealing with the development of the embryo. 371.

Embryo-sac. The megaspore of flowering plants. 234, 248.

Encyst. To surround oneself with a cyst. 5.

Endite. Same as endopodite. 102.

Endoderm (Gr. *endon*, inner; *derma* skin). The inner cell-layer derived from the hypoblast. 58.

Endodermis. The bundle sheath, a layer of cells surrounding the vascular bundle or stele. 215, 282.

Endolymph. (Gr. *endon*, inner; Lat. *lympha*, water). The lymph contained in the membranous labyrinth. 369.

Endolymphatic duct. The internal ear is formed as an invagination of the ectoderm, and the endolymphatic duct is the remnant of the original channel of communication with the exterior. 261.

Endophragm. (Gr. *phragma*, partition). The internal skeleton of Arthropods. 99.

Endoplasm. (Gr. *plasma*, anything moulded). See endosarc. 3, 27.

Endopodite. (Gr. *pous*, *podos*, foot). The inner branch of a biramous appendage. 102.

Endosarc. (Gr. *sarx*, flesh). The endoplasm or inner granular portion of a one-celled organism. 3, 27.

Endo-skeleton. The internal skeleton, for example the bones of a Frog, or apodemes of Arthropods. 315.

Endosperm. (Gr. *sperma*, seed). The nutrient tissue produced by the female spore of the flowering plants, 256.

Entĕron. (Gr. gut). The digestive cavity of Diploblastic animals. 56.

Entomophilous. (Gr. *entomos*, insect : *philao*, I love) Insect loving. Term applied to flowering plants pollinated by insects. 244.

Epĭblast. (Gr. *epi*, upon, upper ; *blaste*, bud, hence developing tissue). The outer layer of the gastrula. 65, 376.

Epicoracoid. (Gr. *epi*, upon). 322.

Ĕpĭcrānium. (Gr. *kranion*, skull). The sclerite covering the upper and back part of an insect's head. 148, 173.

Epidermis. (Gr. *derma*, skin). The upper or outer layer of the skin composed of epithelium. 91. In plants the external layer of cells. 221.

Epĭmerŏn. (Gr. *mēros*, thigh). In Crustaceæ the portion of sclerite between the sternum and the pleuron. 100.

Epĭmerum, or Ĕpimeron. In insects, the posterior sclerite in each thoracic pleuron. 147.

Epiphysis. (Gr. *epi*, upon ; *physis*, growth). A separately ossified end of a bone. 319.

Epipodite. 108.

Episternum. (Lat. *sternum*, breast bone). In insects, the anterior sclerite of the thoracic pleura, 147 ; Frog, 322.

Epistōma. (Gr. *epi*, above ; *stoma*, mouth). In Crustaceæ, a sclerite, above the mouth. 115.

Epithēlial cells, Epithēlium. The tissue that covers the external surface lines the cavities, and forms the secreting cells of glands in animals. 91.

Eustachian recess. So called after its discoverer Eustachius. 314.

Evolūtion. (Lat. *evolutio*, an unfolding or unrolling). 34, 133, 384, 392.

Excrētion. The process by which waste products, *excreta*, (Lat. discharges, chaff, siftings of corn) are got rid of. 29.

Exoccipital. (Lat. *ex*, outer ; *occiput* the back of the head). 316.

Exŏpŏdite. (Gr. *exo*, outside ; *pous*, *podos*, leg, foot). The outer branch of a biramous appendage. 102.
Exoskĕlĕton. The outer skeleton. 99.
Extine or Exine. The outer coat of a microspore. 252.
Eye. 365 ; compound, 133.
Facial nerve. The seventh cranial nerve. 367.
Fæces. (Lat. dregs). Excrement, remains of undigested food.
Fat-body. 154, 352.
Femur. (Lat. thigh). 147 ; Bone of thigh, 324.
Fenestra. (Lat. window). 149 ; ovalis, 368.
Ferment. (Lat. *fermentum*, yeast, ferment). A substance capable of setting up definite chemical changes in certain substances with which it comes in contact without itself undergoing change. 36, 50.
Fern. 202.
Fertilisation. The union of a microgamete with a megagamete. 16, 207, 237-255.
Fetus, more often, but less correctly spelled Foetus (Lat. offspring). The embryo before it leaves the womb.
Filament. 247.
Filum terminale. (Lat. terminal thread). The narrow posterior portion of the spinal cord. 360.
Fission. (Lat. *fissio*, a splitting or dividing). The dividing of a cell or lowly organism into two or more equal parts. 5, 35, 49, 225.
Flăgellāta. The group of protozoa furnished with flagella.
Flăgellum. (Lat. a whip, a lash). A motile, whip-like process of a cell 48, 62. The filiform portion of an antenna. 116.
Floret. Diminutive of flower. 275.
Flower. A shoot specially adapted to the bearing of sporophylls. 242.
Flowering plants. The higher plants characterised by the production of seeds. 228.
Fluctuation. 400.
Fontanelles. (Fr.) Gaps in the cranial wall. 316.
Foot, of Fern. 209.
Fŏrāmen. (Lat. an opening. Pl. *foramina*). Intervertebral. 320 ; F. magnum. 397.

Fore brain. The part of the brain developed from the anterior cerebral vesicle. 357.

Frog. 309.

Fronto-parietal. (Lat. *frons, frontis,* the brow or forehead; *paries,* a wall). A bone forming part of the roof and side-wall of the skull. 317.

Fruit. The structure resulting from the changes in the carpel and its neighbouring parts as a consequence of fertilisation. 260.

Fungi. (Lat. *fungus,* mushroom, mould). The phylum of plants characterised by the absence of chlorophyll. 387.

Funicle. 248.

Furca. (Lat. a fork). A fork-shaped apodeme in the thorax of an insect. 146.

Galĕa. (Lat. a leather helmet). One of the distal processes of an insect's maxilla. 152.

Gamete. (Gr. *gamĕtēs,* husband, *gamĕtē,* wife). A sexual or conjugating cell. 16, 45.

Gametophyte. (Gr. *phyton,* plant). The sexual or gamete-bearing phase of a plant. 46, 203, 251.

Gamopetalous. (Gr. *gamos,* united). Having the petals united to one another, as in Torenia and Sunflower.

Gamosepalous. (Gr. *gamos,* united). Having the sepals united to one another.

Ganglion. (Gr. a knot). A knot-like group of neurones or nerve-cells. 128.

Gastric. (Gr. *gaster,* the stomach). Pertaining to the stomach. 125.

Gastric mill. 125.

Gastrolith. (Gr. *lithos,* stone). A calcareous concretion found in the stomach of many Crustaceans.

Gastrŭla. (Lat. diminutive of stomach). The two-layered or cup-shaped stage of the embryo formed by the invagination of part of the blastula. 65, 137.

Gemma. (Lat. a bud). Gemmation; the process of budding. 37, 63.

Gena. (Lat. the cheek). In insects, that part of the exoskeleton situated behind and below the eyes. 148.

Generation. Alternation of. 46, 227, 256.

Gēnus, pl. Gĕnĕra. (Lat. *gĕnus*, race, family). A group of allied species. 386.

Germinal spot. The nucleolus of an ovum. 65.

Germinal vesicle. The nucleus of an ovum. 65.

Germplasm. (German, *keimplasm*). The substance in the reproductive cells, which carries the hereditary qualities.

Gill. (G. pronounced *hard* as in *goat*, *not* soft as in *gin*). The respiratory organs of many aquatic animals. 106, 382.

Girdle, pectoral. 321 ; pelvic, 323.

Girdle bone. The sphenethmoid. 316.

Gizzard. (G. *hard*). A thickened muscular portion of the alimentary canal. 79, 157.

Gland. An organ which produces a secretion or excretion.

Glenoid cavity. (Gr. *glene*, a cavity ; *oidos*, like). The cavity in the pectoral girdle with which the head of the humerus articulates 321.

Gloea. (Gr. *gloia*, glue, jelly). 59.

Glossopharyngeal nerve. (Gr. *glossa*, the tongue). The ninth cranial nerve. 364.

Glottis. (Gr.) The slit-like opening into the respiratory tract. 314.

Gnathite. (Gr. *gnathos*, jaw). A jaw-like appendage ; 113.

Gŏnad. (Gr. *gŏne*, seed, birth, womb). An organ which produces gametes. 15, 16.

Gŏnapŏphysis. (Gr. *apophysis*, process, projection). A process on the posterior abdominal segments of insects for facilitating copulation or the laying of eggs (ovipositor). 160, 187.

Gŏnĭdangium. (Gr. *angion*, case, vessel). The cavity in which gonidia are produced. 42.

Gŏnĭdia. (Gr. *gone*, seed ; *oidos*, like). Cells in all respects resembling spores, except that they are borne on the gametophyte, not on the sporophyte. 43.

Green gland. The renal organ of some Crustaceæ. 127.

Growing point. The apical meristem. 217, 219, 279, 299, 341.

Guard cells. The cells enclosing the stomata of plants, 221, 280.

Gullet. The œsophagus. 123, 343.

Gymnosperm. (Gr. *gymnos*, naked ; *sperma*, seed). Those flowering plants like Cycads and Pines, which have the seeds naked and not enclosed in the carpel. 228, 240.

Gynaecium (Gr. *gyne*, female ; *oikos*, house). The pistil. 247.

Haemocoele. (Gr. *haima*, blood ; *koilos*, hollow). The body cavity, when it consists, not of a true cœlome, but of blood spaces as in the Arthropods. 135, 154.

Hāēmoglobin. (Gr. *haima*, blood : Lat. *globus*, corpuscle). The red coloring substance of the blood. 80, 341.

Hallux. (Lat. great toe). 324.

Halters, or Halteres. (In Greek, the balancers or light dumb-bells, carried by runners in a race.) The rudimentary structures replacing the posterior wings of the Diptera. 180.

Heart. 81, 121, 337.

Hemispheres. (Gr.) So called from their shape in the human brain. 357.

Hĕpătŏ-pancrĕas. (Gr. *hepar*, liver). 122.

Herb. 263.

Heredity. The property in virtue of which the offspring tends to resemble its parents. 387.

Hermaphrodite. Gr. *hermes* and *aphrodite*, the god Mercury and goddess Venus, famed for their sexual vigor, hence organisms that possess both male and female gonads. Monoecious.

Hibernation. (Lat. *hiberna*, winter). The habit of lying dormant during the cold weather or periods of drought. 66, 310.

Histŏlogy. (Gr. *histion ;* a tissue or web ; *logos*, science). Minute or microscopic anatomy. 59, 279.

Holoblastic. (Gr. *hŏlos*, whole, complete ; *blaste*, reproduction). A term applied to an egg, when segmentation affects the whole ovum. See Meroblastic. 136, 375.

Holophytic. (Gr. *phyton*, plant). A term applied to the method of nutrition of the higher plants. Wholly vegetal nutrition. 19.

Holozōic. (Gr. *zōŏn*, animal). " Wholly animal ; " a term applied to the method of nutrition of animals, requiring ready-made proteid as food.

Hōmōlĕcīthăl. (Gr. *hŏmos*, same, common ; *lĕkithon*, yolk). A term applied to ova in which the yolk is evenly distributed.

Hōmŏlŏgous. (Gr. *homologos*, agreeing with). Arising from the same embryonic structure, of common origin, constructed on the same plan, though not necessarily performing the same function, *e.g.*, the wing of a bird, the arm of man and fore limb of a horse are all homologous.

Host. An organism upon which another is parasitic.

Hyaline. (Gr. *hyalinos*, transparent, glassy). Clear, free from granules.

Hybrid. 408.

Hydra. (Gr. A mythical serpent with many heads). 55.

Hyoid. (Gr. hyon, the Greek letter U ; *oidos*, like). The human bone is U-shaped. 318.

Hypertrŏphy. (Gr. *hyper*, above) indicating excess ; *trŏphe*, nourishment. An excessive increase in size.

Hypha. (Gr. *hyphaino*, to weave). A fungus filament. 42.

Hypoblast. (Gr. *hypo*, under, lower ; *blaste*, developing tissue). The inner layer of the gastrula. 65, 137, 377.

Hypoderma. Hypōdermis. (Gr. *hypo*, below ; *derma*, the skin). In plants the layer of cells below the epidermis. This term is uselessly and stupidly applied by Entomologists to the epidermis of Insects. Formerly the cuticle was mistaken for the epidermis.

Hypogastric. (Gr. *hypo*, under ; *gaster*, the belly). Pertaining to the lower part of the belly. Hypogastric artery. 337.

Hypopharynx. The tongue in insects. 174.

Hypostōme. (Gr. *stoma*, mouth). That portion of a Hydra-like animal above the insertion of the tentacles and below the mouth. 56.

Ileum. Gr. *ilein*, to twist. The lower, convoluted part of the small intestine. 157, 344.

Ilium. (Lat, *ilia*, the flanks, the groin). A bone in the pelvic girdle lying dorsal to the acetabulum. 324.

Imāgo. The winged adult stage of Insects.

Indūsium. (Lat. a lady's under-garment). The membrane covering a sorus, 223.

Infundibulum. (Lat. a funnel). A funnel-shaped projection from the ventral surface of the thalamencephalon. 359.

Infusōria. A class of Protozoa, so called because often found in infusions. 25.

Inglūvĭes. (Lat. the crop, maw). 157.

Innominate vein. (Lat. having no name). 330.

Integument. (Lat. *integumentum*). A covering, skin. 99.

Intercellular spaces. 291, 292.

Internode. (Lat. internodium). A space between two nodes. The portion of a stem or branch between the attachment of successive leaves. 243.

Intestine. Earthworm. 79, Panulirus. 123. Cockroach. 155. Frog. 334. Mosquito. 183.

Intussusception. (Lat. *intus*, within ; *suscipio*, to take up). The intercalation or addition of new matter to the interior or between previously existing molecules.

Iris. (Gr. the rainbow). The anterior part of the choroid forming the coloured curtain of the eye. 367.

Irritability. The property of reacting to a stimulus. 7.

Ischiŏpodite. (Gr. *ischion*, hip ; *pous*, *podos*, leg). The proximal joint of the endopodite. 109.

Ischium. (Gr. *ischion*, the hip). 324.

Iter. (Lat. passage). The ventricle of the mid-brain. 356, 359.

Jaw. 106. Upper, 317 ; Lower, 318.

Jugular. (Lat. *jugulum*, the throat). Pertaining to the throat. Jugular veins (external and internal). 330.

Karyōkĭnēsis. (Gr. *karyon*, kernel, nucleus ; *kinēsis*, movement). The movements or evolutions which the parts of a nucleus pass through in indirect division. 225.

Katabŏlism. (Gr. *katabole*, a laying down, a paying out). Destructive metabolism in which energy is given out. 7.

Kidney. The renal or excretory gland of higher animals. 347.

Knop's solution. 18, 39.

Labellum. (Lat. a little lip). The distal portion of a Mosquito's labium. 175.

Labium. (Lat. lip). A lip. The united second maxillae of an insect. 152.

Labrum. (Lat. the upper lip). 148, 174.

Lăcĭnĭa. (Lat. a strip, flap). The inner division of the maxilla in insects. 152.

Lamella middle. (Lat. thin sheet or layer). A modification of the cell-wall consisting of a compound of pectic acid and calcium, between adjacent cells. 213.

Lamina. (Lat.) A thin scale or plate.

Larva. (Lat. mask). The free-living young of an animal which undergoes metamorphosis. 138, 190.

Leucocyte. (Gr. *leukos*, white ; *kytos*, cell). A white blood corpuscle. 1, 80, 341.

Lignin. (Lat. *lignum*, wood). A material characteristic of the wall of wood cells.

Liver. 344.

Lumbricĭdae. (Lat. *lumbricus*, earthworm). A family of Earthworms. 96.

Lūmen. (Lat.) The hollow of a duct or tube.

Lung. 347. Development of. 382.

Lymph. 342.

Lymphatic vessels. 342.

Lymph hearts. 312, 342.

Lymph spaces—Subcutaneous, 343, Subvertebral. 343.

Macrogamete. Same as megagamete. 15.

Macronucleus. Same as meganucleus. 30.

Macroscopic. (Gr. *makros*, long, large ; *skŏpeo*, to look). The appearance as seen with the naked eye.

Macrospore. Same as megaspore. 241, 248.

Maize. 268.

Malaria. 171.

Malpighian tubes. Called after their discoverer Malpighi, (*gh.* pronounced hard as in *ghost*). The urinary tubules of insects. 159, 183.

Mammals. (Lat. *mamma*, breast). Vertebrates that suckle their young. 386.

Mandible. (Lat. *mandĭbŭla*, jaw). The anterior mouth appendage of Arthropods. 114, 151, 174. The lower jaw of Vertebrates. 318.

Maturation of the Ovum. The preparation of the ovum for fertilisation by reducing division of the nucleus and extrusion of the polar bodies. 373.

Maxilla. (Lat. jaw). 114, 151, 318.

Maxilliped. (Lat. jaw-foot). 108.

Meckel's cartilage. 318.

Mĕdulla. (Lat. marrow, pith). The central portion as opposed to the cortex or peripheral portion. 27, 281. Oblongata. 359.

Medullary rays. Radial strands of ground tissue connecting the cortex with the pith. 281.

Mĕgăgamete. (Gr. *megas*, great ; *gamĕtē*, wife, spouse). The female, usually the larger, conjugating cell. The ovum. 15.

Meganucleus. The larger nucleus of Infusoria. 30.

Megascōlex. (Gr. *megas*, long ; *skōlēx*, worm). A genus of Earthworms, some of which are of great size. 96.

Megaspore. The larger spore in plants that are heterosporous, and which gives rise to a prothallus bearing female gametes. 234, 242, 249.

Membrane. A thin sheet or layer of tissue.

Membrane bone. Bone which does not replace pre-existing cartilage. 316.

Mendel. 408.

Meninges. (Gr. *meninx*, a membrane). The three membranes that cover the brain and cord. 362.

Mentum. (Lat. chin). The fused stipes of the second maxilla or labium of insects. 152.

Merismatic. (Gr. *mĕrismos*, division). Having the qualities of meristem. 279, 285.

Meristem. (Gr. *meristēs*, divider). Tissue of embryonic character which preserves the power of multiplying. 217, 279, 285.

Meroblastic. (Gr. *mĕros*, part ; *blaste*, bud). A term applied to ova in which segmentation is only partial as in the egg of the Fowl.

Mērŏpŏdite. (Gr. *mēros*, thigh). One of the segments of a Crustacean appendage. 109.

Mĕsĕntĕrŏn. (Gr. *mesos*, middle ; *enteron*, gut). The mid-gut. That portion of the alimentary canal derived from the archenteron, and lined with hypoblast. 124, 156.

Mesentery. The fold of peritoneum by which the gut is suspended in the coelome. 77, 327.

Mesoblast. The middle embryonic layer of Triploblastic animals. 59, 77, 137, 377.

Mesoderm. The mesoblast. 59, 377.

Mesoglœa. (Gr. *gloia*, jelly). A term often given to the glœa. 59.

Mesonotum. 145, 177.

Mesophyll. (Gr. *phyllon*, leaf). The green parenchyma of leaves. 222, 232.

Mĕtabŏlism (Gr. *metabole*, change). The processes concerned in the construction and breaking-up of protoplasm, 7.

Metacarpal bones. (Gr. *meta*, beyond ; *karpos*, the wrist). 323.

Metamere. (Gr. *mĕta*, behind, indicating repetition ; *mĕros*, part). A somite. One of a series of homologous segments more or less resembling one another, placed one behind the other of which certain animals such as Annelids and Arthropods are composed. 70.

Metamorphosis. (Gr. change of form). 195.

Metanotum. 145-178.

Metastoma. (Gr. *meta*, behind ; *stoma*, the mouth). A process behind the mouth in Crustaceae. 114.

Metatarsal bones. (Gr. *meta*, beyond ; *tarsos*, the instep). 324.

Metazoa. (Gr. *meta*, later ; *zoon*, animal). " The later animals " composed of several cells ; all animals other than the Protozoa. 59.

Microbe. (Gr. *mikros*, small ; *bios*, life). A microscopic organism, whether animal or plant. 54.

Micrococcus. (Gr. *kokkos*, berry). A globular or berry-shaped bacterium. 53.

Microgamete. The smaller, *i.e.*, the male gamete. 15.

Micro-millimetre, or micron. The one-thousandth part of a millimetre the 1-25,oooth of an inch, often written, μ.

Micro-nucleus. The small nucleus of Infusoria. 30.

Micro-organism. A microbe. 54.

Micropyle. (Gr. *pyle*, gate, entrance). The small opening in the seed coat. 234.

Micro-sporangium. (Gr. *angeion*, vessel). The cases, such as pollen-sacs in which microspores are developed. 236, 247.

Microspore. The smaller or male spore of those plants which produce two kinds of spore. Pollen grain. 242.

Mitosis. (Gr. *mitos*, a thread). Karyokinesis. 225.

Moniliform. (Lat. *monile*, a necklace). Beaded like a necklace.

Monocotyledon. 267, 268.

Monoecious. (Gr. *monos*, single ; *oikos*, dwelling). Having the male and female gonads on the same individual. Hermaphrodite. Having micro and megaspores on the same plant.

Morphology. (Gr. *morphe*, shape ; *logos* science). The science which treats of the shape and structure of organisms.

Morŭla. (Lat. a little mulberry). A mulberry-shaped ball of cells resulting from the segmentation of an ovum. 65, 375.

Mosquito. 167.

Mucor. (Lat. mould). 42.

Muller's Duct. 350.

Muscle—process, Hydra. 59.

Mutation. 400.

Mycēlium. (Gr. *mykes*, mould, fungus). A branching mass of hyphae 42.

Myoneme. (Gr. *mys*, muscle ; *nema*, thread). The contractile striae of certain Protozoa. 28.

Nares. (Lat. the nostrils). 312.

Nasal bone. 317.

Nauplius. A larval stage of many Crustaceae. 138.

Nemathelmintha. (Gr. *nema*, *nematos*, thread ; *helminthos*, worm). A phylum of thread-shaped worms. 95.

Nematoda. (Gr. *oidos*, like). The thread-like worms. 95.

Nematocyst. (Gr. *kystos*, a sac). The sac in which a stinging thread is held. 58.

Nĕphridium. (Gr. *nephros*, kidney ; *oidos*, like). An excretory organ, with an internal opening in the coelome, an external on the surface of the body. 90.

Nephrōdium. A genus of Ferns, perhaps so called from the kidney-shaped indusium. 210.

Nephropore. Nephridiopore. (Gr. *poros*, passage). The external opening of a nephridium. 90.

Nephrostome. (Gr. *stoma*, mouth). The mouth or opening into the coelome of a nephridium. 90.

Nerve. 89.

Nervure. 146, 179.

Neurenteric canal. (Gr. *neuron*, a nerve ; *enteron*, gut). 380.

Neuron. Neurone. (Gr. nerve). A complete nerve cell including all its processes. 89.

Node. (Lat. *nodus*, knot). The part of a stem or branch from which a leaf or leaves arise. 243.

Notochord. (Gr. *notos*, the back ; *chorde*, a string). A rod of hypoblastic cells found in the embryos of Vertebrates and in the adult forms of some animals lower than the Vertebrates. 378.

Notum. (Gr. *notos*, back). A term usually given to the thorcic terga of an Insect. 145.

Nucellus. (Lat. *dim.* a little nut). The inner mass of an ovule. 234, 248.

Nucleus. (Lat. a kernel). 4, 11, 30, 225.

Nucleus. Division of, 225.

Nucleolus. (Lat. diminutive of *nucleus*).

Nutrition. Of Amœba 3. Paramœcium, 30. Spirogyra, 19. Plants, 21.

Nymph. The young stage of an insect that does not undergo metamorphosis from the leaving of the egg to the winged stage, *e.g.*, a young Cockroach. 166.

Occipital condyle. (Lat. *occiput*, the back of the head ; Gr. *kondylos*, knuckle). 316.

Ocellus. (Lat. a little eye). An eye-spot. The simple eye found in many Insects. 149.

Oculo-motor nerve. (Lat. *oculus*, the eye). The third cranial nerve. 363.

Oesophagus. (Lat.) The gullet. 78.

Olecranon. (Gr. *olene*, elbow ; *kranion*, head). 323.

Oligochaeta. (Gr. *oligos*, few ; *chaeta*, bristle). A sub-class of the bristled worms, so called because those first studied had few bristles on each somite, 96.

Ŏmmatidium. (Gr. diminutive of *omma*, eye). Each of the ocelli that make up the compound eye of Arthropods. 134.

Omosternum. (Gr. *omos*, the shoulder ; *sternon*, the breast-bone). 322.

Ontogeny. (Gr. *ontos*, individual ; *genesis*, creation). The life history of the individual. 389.

Oocyte. (Gr. *oon*, egg ; *kytos*, cell). 373.

Oogonia. (Gr. *oon*, egg ; *gone*, seed, womb). The cells that result from the repeated division of the primitive germ-cells of the ovary. 373.

Ōŏsperm. (Gr. ōŏn, egg ; *sperma*, seed, sperm). The zygote formed by union of sperm and egg. 374.

Operculum. (Lat. a lid). 381.

Ōral. (Lat. *os, oris*, mouth). Pertaining to the mouth.

Order. 387.

Organ. (Gr. *organon*, instrument). A portion of the body adapted for the performance of a special function. 33.

Organism. Any living individual, plant or animal.

Orthŏptĕra. (Gr. *orthos*, straight ; *ptera*, wings). The order of insects which includes Cockroaches and Locusts. 141, 143.

Ossicle. (Lat. ossiculum, a little bone). 125.

Ostium. (Lat. door, mouth). An aperture into the heart of Arthropods. 118.

Ōvary. (Lat. *ovum*, egg). In animals, the female gonad. In flowering plants, the hollow portion of the carpel. 247.

Oviduct. The duct of the ovary.

Ovipositor. (Lat. *positor*, a placer). 145, 188.

Ovule. The megasporangium of flowering plants. 234.

Ovum. The egg-cell, female gamete. 16, 373.

Palĭnūrus. The spiny Lobster or Crawfish of Europe 97.

Palisade. 232, 292.

Palp. A feeler, the exopodite of an insect's maxilla. 152.

Pancreas. (Gr. the sweetbread). One of the digestive glands. 122

Panulīrus. The Indian genus of spiny Lobster. 97.

Păpilla. (Lat. nipple). A small nipple-like projection.

Paraglossa. (Gr. *para*, beside ; *glossa*, tongue). One of the distal parts of the insect's labium. 152.

Paramōēcium. 25.

Parasīte. (Gr. *parasitos*, one who sits at another's table ; a flatterer). Organisms, which live within or upon others and draw their nutriment from them. 50.

Parasphenoid. (Gr. *para*, near). 317.

Parenchyma. (Gr. something poured in beside). A soft tissue generally ; especially vegetable tissue with soft, non-woody cell walls not much longer than they are broad and containing protoplasm.

Parĭetal. (Lat. *pariĕs*, a wall). The outer wall, especially the outer wall of a space formed by two layers. 317, 328.

Parthĕnŏgenĕsis. (Gr. *parthenos*, virgin ; *gĕnesis*, birth). Development from an unfertilised ovum, *i.e.*, without the aid of a male gamete.

Pasteur's fluid. 39.

Pătagium. (Lat. a border or frill on a lady's coat). A moveable epaulette-like process on each side of the pronotum, well marked in Moths and Butterflies, rudimentary in Mosquitoes. 178.

Peduncle. The stalk of a flower or fruit.

Penis. (Lat.) The male copulatory organ. 160, 186.

Peptōne. (Gr. *pepto*, to digest). A diffusable proteid, such as is formed after the action of digestive fluids on albumen. 127, 344.

Perianth. (Gr. *peri*, around ; *anthos*, flower). The envelope whorls of a flower surrounding the sporophylls. 244.

Pericardium. (Gr. *peri*, around ; *kardion*, heart). The sac or cavity in which the heart is situated. 118.

Perichæta. (Gr. *chaeta*, bristle). A genus of earthworm, each of whose somites is surrounded with bristles. 67, 70.

Pericycle. (Gr. *kyklos*, circle, circumference). The outer layer of cells of the stele, internal to the endodermis. 296.

Perionyx. (Gr. *onyx*, nail, bristle). A genus of earthworms, like Perichæta surrounded with setœ. 70, 95.

Perisperm. In a seed, the remains, if any, of the nucellus which are not absorbed during development. 256.

Peristŏme. (Gr. *stoma*, mouth). The segment surrounding the mouth. 70.

Peritŏnēum. (Gr. *tonos*, a spread or stretched band). 77, 327.

Petal. (Gr. *petalos*, spread out flat). The individual leaves of the corolla.

Petiole, the leaf-stalk. 244.

Phagocyte. (Gr. *phagos*, eater, glutton; *kytos*, cell). White blood cells and others that eat up and remove injurious matters from the body. 197.

Phalanges. (Gr. *phalanx*, a row). The bones of the digits. 324.

Phanĕrŏgams. (Gr. *phaneros*, evident, flaunting; *gamos*, marriage). The flowering plants, so called from the conspicuous appearance of the sporophylls and their envelopes. 228, 240.

Pharynx. (Gr. the throat). The portion of the alimentary canal at the junction of the buccal cavity with the oesophagus. 78.

Pheretima. A genus of earthworms. 66.

Phlöem. (Gr. *phloios*, bark, bast). 282.

Photosynthĕsis (Gr. photos, light; *synthesis*, construction). The construction of starch or sugar by the chloroplasts in the presence of sun-light. 23.

Phylogeny. (Gr. *phylon*, race, tribe; *genesis*, origin). The history of the evolution or development of a race. 389.

Phyllosŏme. (Gr. *phyllon*, leaf; *soma*, body). The leaf-like larva of Panulirus and some other crustaceans. 138.

Phyllotaxis. (Gr. Leaf-arrangement). 262.

Phylum=Sub-kingdom. 387.

Physiology. (Gr. *physis*, nature, constitution; *logos*, science). The science which treats of functions.

Pia mater. (Lat. pious mother). A delicate vascular membrane investing the brain and spinal cord. 362.

Pineal body and stalk. 359.

Pinna. 231.

Pistil. 247.

Pithing. The operation of destroying the "pith" or medulla oblongata. 313.

Pituitary body. (Lat. *pituita*, mucus, phlegm). A rounded body attached to the tip of the infundibulum. 359.

Placenta. (Lat. a flat cake). The after-birth which is shaped like a flat cake in human beings. Hence generally the place to which seeds, etc., are attached and through which they obtain their nutrition. 248.

Plasma. (Gr. substance). The fluid part of blood.

Plasmolysis. (Gr. *lysis*, loosening, setting free). The contraction and separation of protoplasm from the cell-wall caused by the withdrawal of water. 11.

Platyhelminthes. (Gr. *platys*, flat; *helminthos*, worm). The Flat Worm phylum. 95.

Pleopod. (Or. *pleo*, to swim; *pous*, *podos*, foot). A swimmeret or swimming foot. 101.

Plēūrobranchia. (Gr. *branchia*, gill). A gill attached to the pleuron. 107.

Pleuro-peritoneum. 327.

Pleuron. (Gr. side). Of Crustacea. 101. Of insects. 143.

Plexus. (Lat. a network). A network of blood vessels or nerves.

Plūmūle. (Lat. a little feather). The embryo shoot in a seed. 259.

Pneumogastric nerve. (Gr. *pneuma*, lung; *gaster*, stomach). The Vagus or tenth cranial nerve which supplies the lungs and stomach. 365.

Podical. (Lat. *pōdex*, *podicis*, the anus). Anal, 144.

Pŏdobranchia. (Gr. foot-gill). A gill attached to a limb. 107.

Pŏdomere. (Gr. *pous*, *podos*, foot, *mĕros*, part). A segment of an appendage. 101, 147.

Polar bodies or cells. The portion (cells) of the ovum cast off in the process of maturation or reducing division. 373.

Pŏllen, (ŏ short as in *doll*). (Lat. flour, dust). The microspores of flowering plants. 236, 252.

Pollex. (Lat. the thumb).

Polychætæ. (Gr. many-bristled). A sub-class of worms. 95.

Portal system. (Lat. *porta*, a gate). A network of capillaries interposed in the course of a vein. Hepatic portal. 331. Renal portal. 332.

Prawn. 97.

Precoracoid. (Lat. *pre*, before). 321.
Pre oral. (Lat.) In front of the mouth.
Premandibular. In front of the mandible. 148.
Primine. The outer coat of an ovule.
Primitive. In biology, low, early, showing little differentiation. 33, 391.
Primordial ūtricle. (Lat. *utriculus*, a little skin). The layer of protoplasm surrounding the vacuole and in immediate contact with the cell-wall. 11.
Probŏscis. (Lat. snout) of mosquito. 176.
Process. (Lat. *processus*). In anatomy, a projecting portion, a prolongation.
Proctodăēum. (Gr. *proktos*, anus; *odaion*, passage). The hind-gut 124.
Prōnotum. (Gr. *pro* in front; *notum*, back). The anterior thoracic tergum. 145, 178.
Prōnucleus. A gamete nucleus. 207, 253, 254, 374.
Pro-otic. (Gr. *pro*, before; *otos*, ear). A bone developed in front of the auditory capsule. 316.
Prophloem. The first-formed phlöem.
Propòdíte. 110.
Prŏstate. (Lat. *pro*, in front; *status*, standing). An accessory male organ. 86, 160.
Prōstōmium. (Gr. *pro*, in front; *stomion*, mouth.) A process or segment in front of the mouth. 71.
Proteid. 7.
Prōthallus. (Gr. *thallos*, sprout). The gametophyte of the higher plants. 203, 235, 255.
Prōthorax. The anterior somite of the thorax. 145, 176.
Prōtista. (Gr. *protos* first, primitive; *ista* beings). The most primitive unicellular organisms which it is difficult to call definitely either animal or plant. 49, 384.
Prōtŏphyta. (Gr. *protos*, first, earliest; *phyton*, plant). The most primitive, unicellular plants.
Protoplasm. (Gr. *protos*, first, primitive; *plasma*, something moulded). 8.

Prōtopodite. The stem of a biramous appendage. 101.
Prōtozoa. (Gr. *zoa*, animals). The unicellular animals. 1, 387.
Prŏxĭmăl. Nearest the organic axis ; nearest the point of attachment.
Prōxylem or Protoxylem. (Pronounced prōzylĕm.) (Gr. *xylon*, wood). The first formed wood-vessels or tracheids. 216.
Pseūdŏpŏd. (Gr. *pseudes*, false ; *pous*, *podos*, foot). A temporary and constantly-changing process thrown out by an amœboid cell. 3
Pterygoid. (Gr. *pteryx*, *pterygos*, a wing). A bone in shape faintly resembling a wing. 318.
Pubes. (Lat. *pubes*, hair). So called because this region in Man is covered with hair. 324.
Pulmonary. (Lat. *pulmo*, the lung). Pertaining to the lung. 333.
Pŭlvillus. (Lat. a little cushion). A pad between the claws on the distal joint of an insect's leg. 147.
Punctum Vegetationis. Latin for the growing point. 217.
Pūpa. (Lat. *a girl*, a doll). A stage usually quiescent between the larva and the imago of an insect. A chrysalis. 192, 197.
Pūtrefaction. 5, 49.
Pylōrŭs. (Gr. a gate-keeper, a darwan). The end of the stomach furthest from the mouth. 124, 343.
Pyrenoid. (Gr. *pyrēn*, the stone of a fruit ; *oidos*, like). 13.

Quadrate. (Lat. *quadratus*, right angled). 318.
Quadrato-jugal. (Lat. *quadratus*, right angled ; *jugum*, yoke). 318.

Radicle. (Lat. *radicula*, a little root). The embryo root. 239, 259.
Radio-ulna. (Lat. *radius*, a spoke or ray ; and ulna). 323.
Rana tigrina. 309.
Recapitulation theory. 133.
Recessive. 409.
Rectum. (Lat. straight). The portion of gut nearest the anus. 344.
Reducing Division. 225, 372.
Rejuvenescence. (Lat. *rejuvenesco*, to grow young again). 30.
Rēnal. (Lat. *ren*, kidney). Pertaining to the kidney. 332.
Reptiles. (Lat. *repto*, I crawl). A class of Vertebrates including snakes, lizards, crocodiles, tortoises and the like. 309, 386.
Respiration. 8, 41, 120, 346.

Retina. (Lat. *rete*, a net). The innermost and sensitive coat of the eye-ball, in which the fibres of the optic nerve form a net work 367.

Retinula. (Lat. a little retina). 135.

Rhīzoid. (Gr. *rhiza*, root ; *oidos*, like). 203.

Rhīzōme. (Gr. *rhizoma*, a root stock). A root-like, generally underground, stem. 202.

Root. 218, 295.

Root Cap. 220, 298.

Root-pressure.

Rut. The season or state in which the female seeks the male. 28.

Sacchărŏmycĕs. (Gr. *sakcharon*, sugar ; *mykes*, fungus). The yeast plant. 35.

Salivary glands. Cockroach. 158. Mosquito. 184.

Saprophyte. (Gr. *sapros*, rotten ; *phyton*, plant). A plant that obtains its nutrition from decomposing proteids. 5, 50.

Scaphŏgnathite. (Gr. *skaphe*, hull of a ship ; *gnathos*, jaw). The scoop-like organ with which Palinurus, etc., bale water out of the gill-chamber. 98, 114.

Scapula. (Lat. the shoulder-blade). 212.

Schūlze's solution (pronounce *schūl—tze*) of chloro-iodide of zinc. 12 Macerating. 213.

Sciatic. (Gr. *ischion*, the hip). Pertaining to the hip. 360.

Sclera. (Gr. *skleros*, hard). The tough outer coat of the eye-ball. 366.

Sclērenchyma. (Gr. *skleros*, hard ; *enchyma*, tissue). A tissue the cells of which have their walls thickened and lignified. 211.

Sclērite. A specially hardened portion of cuticle. 99, 143.

Scūtellum. (Lat. *scutulum*, a little shield). Portion of the mesonotum in certain insects. 177. Absorbent region of the cotyledon. 261.

Secundine. The inner coat of the ovule.

Seed. The fertilized megasporangium (ovule) containing the embryo of a flowering plant. 239, 257.

Segmental cells. The cells last cut off from the apical cell. 218.

Segmentation. (1) The division of the body into metameres. 70. (2) The division of the ovum into a number of cells or blastomeres. 375.

Sepal. An individual leaf of a calyx. 244.

Septum. (Lat. fence, wall). A partition. 77.

Sessile. (Lat. *sessilis*, fit for sitting on, with a broad base). Without a stalk. 234, 248.

Sēta. (Lat.) A bristle, a stiff hair. 94.

Sex, 14.

Shoot. In plants an axis, stem or branch with its leaves. 261.

Shrub. 263.

Sieve-tissue. Tubes, plates. 215, 282.

Sinus. (Lat. a curve, fold, bay. A hiding place). Often applied to a large space or cavity containing blood or lymph. 120. S. Venosus. 337.

Somatic. (Gr. *sōma*, body) (1) Applied to the vegetative characters or cells of the body as contrasted with the reproductive. (2) Applied to the layer of mesoderm in contact with the ectoderm; parietal, in contrast with the splanchnic. 77.

Sōmīte. A metamere, body segment. 70, 100.

Sōrus. (Lat.) A collection, *e.g.*, of sporangia. 211, 223.

Spawn. The conglomerated eggs of fish or frogs when laid. 352.

Species. (Lat. appearance, likeness, sort). Collection of individual organisms closely related and resembling one another in all essential points. 385.

Spermathēca. (Gr. *sperma*, seed; *theke*, vessel). A sac or reservoir in a female or hermaphrodite animal in which semen from another animal is stored. 84.

Spermato-genesis (Gr. *genesis*, origin). The development of the male gametes from the sperm-mother-cells. 372.

Spermatozoid. (Gr. *oidos*, like). In plants, male gametes, motile like spermatozoa. 16, 207, 237, 253.

Spermătōzōōn. Pl. zoa. (Gr. *sperma*, seed, semen; *zoon*, animal). Male gametes of animals. 16, 64, 373.

Spermiducal glands. (Lat. *ducalis*, leading, relating to a duct). In some worms glands usually in connection with the sperm ducts, "Prostates." 86.

Sphenethmoid. Pertaining to the sphenoid (Gr. *sphen*, a wedge; *oidos* like) and ethmoid (Gr. *ethmos*, a sieve). The sphenoid is inserted like a wedge in the base of the human skull. The ethmoid of man is perforated in many places to allow the branches of the olfactory nerve to pass through, and so resembles a sieve. 316.

Sphincter. 331.

Spinal cord. The part of the central nervous system which is enclosed in the canal of the spinal column. 360.

Spinal nerves. The nerves arising from the spinal cord. 360.

Spīracle. (Lat. *spiro*, to breathe). The openings of the tracheæ. 144.

Spirogyra. 10.

Splanchnic. (Gr. *splanchnon*, gut, viscus). Visceral. The layer of the mesoderm in contact with the endoderm. 77, 380.

Spleen. 353.

Sporangium. (Gr. *spora*, seed, spore, *angeion*, case). The spore case. 223.

Spore. An asexual reproductive cell. 5, 36, 46, 50.

Sporophyll. (Gr. *phyllon*, leaf). A leaf that bears spores. 233, 246.

Sporophyte. (Gr. *phyton*, plant). The asexual phase of a plant which bears spores. 46, 209, 257.

Sport. 399.

Sporulation. The process of dividing into spores. 5.

Squamosal. (Lat. *squama*, a scale, because in Mammals it is scale-shaped). 317.

Stamen. (Lat. a thread). The male sporophyll of a flowering plant. 247.

Starch. 12, 20.

Statocyst. 117.

Stegomyia. 172.

Stele. (Gr. a column). A strand of tissue surrounded by an endodermis and containing one or more vascular bundles. 212.

Sternum. (Lat. breast bone). 322. In Arthropods, a ventral sclerite. 100, 143.

Stigma. *pl.* stigmăta. (Gr. spot). In flowering plants, that portion of the carpel which receives the pollen. 247. A spiracle, or breathing aperture in insects. 144.

Stimulus. (Lat. a spur). Anything that can excite reaction. 7, 208, 274.

Stipes. (Lat. a stem). The second segment of an insect's maxilla. 151.

Stoma, *pl.* Stomata. (Gr. mouth). The openings between two guard-cells in the epidermis communicating with the intercellular spaces. 221.

Stomodāēum. (Gr. *odaion*, passage). The anterior part of the alimentary canal formed by the ingrowth of the epiblast. 124, 156, 181.

Style. 144, 247.

Stylopyga. A genus of Cockroaches. 142.

Subclavian. (Lat. *sub*, under). Under the clavicle. 330.

Sucker. In Hydra often called the foot. 55.

Sunflower. 274.

Suprascapula. (Lat. *supra*, above). 321.

Suspensorium. The quadrate. 318.

Suture. (Lat. *sutura*, a seam). A line of junction between parts of the exoskeleton of an Arthropod or bones of the Vertebrate skull. 148.

Symbiōsis. (Gr. living with or together). The condition of two organisms living together to their mutual advantage.

Sympathetic nervous system. 365.

Symphysis (Gr. union together). Union without a moveable joint between bones.

Syncarpous. (Gr. *syn.* together; *carpos*, fruit) having the carpels united to one another. 273.

Synergid. (Gr. assistant). An assistant-cell. 251.

Systole. (Gr. a drawing together, a contraction). The phase of contraction in a heart or a vacuole. 29.

Tadpole. The larva of the frog. 380.

Tarsus. (Gr. *tarsos*, the sole). The heel of a Mammal. The distal joints of an insect's leg. 147, 324.

Tegmen. (Lat. a cover). The forewings, the wing covers of Beetles and Orthoptera. 223. Of seeds; the inner coat.

Telson. (Gr. extremity). The terminal portion of a Crustacean's abdomen. 99.

Tentacle. (Lat. *tento*, to handle, feel). 56.

Tentōrium. (Lat. a tent, something stretched over). An apodeme or chitinous framework within the head of an insect on which the brain rests. 149.

Tergum. (Lat. the back). A dorsal sclerite. 99, 143.

Testa. (Lat. tile, hard cover). Outer seed coat.

Testis. (Lat. a witness, hence the evidence of virility). The testicle or gonad of male animals. 83.

Thalamencephalon. (Gr. *enkephalon*, the brain). The median part of the fore-brain. 357.

Thalamus. (Gr. marriage-bed, hence, site of origin). (1) The distal end of the flower-stalk from which the floral leaves arise. (2) Part of the brain near which nerves arise. 244.

Thallus. (Gr. shoot.) A plant body undifferentiated into root and shoot.

Thorax. (Gr. the chest). 145.

Thymus. 353.

Thyroid. (Gr. *thyreos*, a shield; *oidos*, like). A cartilage of the larynx in man so called from its shape. A gland situated near the cartilage. 353.

Tibia. (Lat. a flute, a shin bone). The fourth segment in an insects leg. 147.

Tibio-fibula. (Lat. *tibia*, a flute; *fibula*, a brooch). 324.

Tissue. A continuous collection of cells in intimate union. 33.

Toad. 309.

Torenia. 273.

Torula. (Lat. a little knot, bulge or elevation). A yeast plant. 35.

Trachēa. (Gr. *tracheia*, the wind pipe). The wind pipe in Vertetrates. The air-tubes in insects. 165. The vessels in the higher vascular plants. 215.

Tracheids. (Gr. *oidos*, like). In plants, elongated cells, looking like and fulfilling the same function as true vessels, from which they differ in being single cells and not a number of cells with a common cavity. 215, 230.

Transfusion. Osmosis. 12.

Transpiration. The giving off of watery vapour from the leaves of plants. 221, 285.

Transpiration current. The upward current of sap from the root to the leaves.

Trīchocyst. (Gr. *thrix, thrikos,* a hair ; *kystos,* a sac). Stinging sacs in the ectoplasm of certain Protozoa. 29.

Trigeminal nerve. (Lat. threefold). So named because it breaks up into three main divisions. The fifth cranial nerve. 364.

Triploblastic. (Gr. *triploos,* triple ; *blaste,* sprout, hence embryonic tissue). Three-layered. Those animals that have a body formed of ectoderm, mesoderm and endoderm. 59.

Trōchanter. (Gr. upper part of thigh). In insects the second segment of the leg. 147.

Truncus arteriosus. The tubular part of the heart from which the arterial arches arise. 339.

Tympanic membrane. 312, 368.

Tympanum. (Lat. a drum). The middle ear is so called because its cavity is bounded on one side by a membrane stretched like that of a drum. 368.

Typhlosōle. (Gr. *typhlos,* blind, without an exit, as a " blind alley ;" *solen,* channel). A longitudinal fold projecting into the lumen of the gut. 79.

Ureter. (Gr. *oureo,* to make water). The duct of the kidney. 348.

Uropod. (Gr. *oura,* tail ; *pous ; podos,* foot). The tail foot. The posterior appendage of a Crustacean. 103.

Urostyle. (Gr. *oura,* the tail ; *stylos,* a rod). A bony rod forming the terminal part of the vertebral column. 320.

Vacuōle. (Lat. *vacuus,* empty). A portion of a cell containing fluid which looks empty. 4, 11, 29.

Vagus. (Lat. wandering). 365.

Valve. A membranous flap inside the heart or a vessel allowing fluid to flow in a definite direction only. 339.

Variation. The tendency in virtue of which organisms vary in slight details from their parents. 388.

Vas deferens, *pl.* vasa deferentia. (Lat. carrying away vessels The duct of the testis which carries away the semen. 85, 122, 350.

Vascular. Pertaining to a vessel, applied to organs richly provided with vessels.

Vascular bundles. 214, 282.

Vas efferens. *pl.* vasa efferentia. (Lat. carrying out vessels.) Ducts leading from the testis to the vas deferens. 349.

Vegetative. Applied to cells or organs, whose function is nutritive or somatic as contrasted with reproductive. 236.

Vein, (a) blood vessel which returns blood to the heart. 328. (b) The nervures of an insect's wing. 146, 179. (c) The vascular strands of a leaf. 267.

Venation. The arrangement of the veins in a leaf or wing. 179, 267.

Venter. (Lat. belly). The hollow portion of an archegonium. 205.

Ventral. Pertaining to the belly. Ventral surface, that surface in animals which, as a rule, is next the ground during progression; of a leaf that side nearest the axis while in the bud, usually the upper surface. The opposite of dorsal.

Ventricle. (Lat. diminutive of *venter*, the belly). Used of any small cavity, as in the heart. 337, or brain, 355.

Vernation. (Lat. *vernalis*, pertaining to spring time). The arrangement of foliage leaves in a bud.

Vertebra. (Lat. a joint); an individual bone of the spinal column. 319.

Vertebrata. (Lat. *vertebratus*, fitted with vertebræ). The phylum of animals that possess vertebræ. 309, 386.

Viscus, *pl.* viscera, Latin for internal organs. 121.

Vesical. (Lat. *vesica*, a bladder). Pertaining to the bladder. Vesical vein. 332.

Vesicle. (Lat. diminutive *vesicula*, a little bladder). Cerebral vesicles—the three enlargements at the fore end of the neural tube. 354.

Vesiculae seminales. (Lat.). Seminal bladders, small sacs in which semen is held. 83.

Vitelline membrane. (Lat. *vitellus*, the yolk of an egg). The membrane surrounding the yolk or egg. 84, 374.

Vitreous. (Lat. *vitreus*, glassy). Vitreous chamber, humour, 367.
Vocal cords. Two elastic folds in the larynx the vibration of which produces the voice. 315.
Vocal sacs. 314, 325.
Vomer. (Lat. a ploughshare. The human vomer is shaped like a ploughshare.) 317.

Wing. 145, 178.
Worms. 94.
Wood. 283.

Xiphisternum. (Gr. *xiphos*, sword ; *sternon*, breast-bone). 322.
Xylem. (Gr. *xylon*, wood). 283.

Yeast. 35.
Yellow cells. 76.
Yolk. 65.

Zygospore, Zygote. (Gr. *zygotos*, yoked, married). The fertilised ovum. The cell which results from the conjugation of the gametes. 15, 46, 65.

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